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THE RELATIONS OF THE EARTH SCIENCES IN VIEW OF THEIR PROGRESS IN THE NINETEENTH CENTURY.[1]

FACTS of earth science have now been so abundantly acquired and so thoroughly systematized that there is some danger of our substituting the schemes in which earth-knowledge has been summarized for first-hand knowledge of the earth itself.

For a fundamental matter like the globular form of the earth we resort to a hand globe, so admirable in its imitation of nature that we must beware lest the little globe rather than the earth in its true dimensions satisfies our imagination. We have so conveniently divided the geological record of the earth's history into ages and periods that their easily repeated names are apt to replace the laborious conception of long divisions of time.

Our escape from the danger of taking scheme for fact has lain in the resort to individual observation, and the past century must long be famous for the extent to which advantage has been taken of the opportunity for outdoor study.

The earth has been explored and measured as never before. The lands have been mapped, the oceans have been charted by original observers. The air has been followed in its circuits, great and small. The structure of the earth's crust has been patiently traced out. Thus "Go and see" came to be our watchwords one hundred years ago. As long as we, like Antæus of old, can return to the earth for new stores of the strength that we find in facts, we need not fear being strangled by any voluminous Hercules of theory.

[1] An address delivered before the Department of Earth Sciences in the World's Congress of Science and Arts at St. Louis, September 20, 1904.

It is the active appeal to observation that has checked the freedom of speculation which our brilliant predecessors enjoyed in an earlier century, when their fanciful schemes were little restrained by the barriers of fact that have since then been built up on every side. Indeed, schemes came to be for a time so much in disrepute that some investigators wished to suppress theorizing altogether, as was seen in the effort to supplant the name "geology" by "geognosy." I rejoice that the effort did not succeed; for if earth science were really limited to facts of direct observation, it would be at best a dreary subject.

How uninspiring would be such a knowledge of tides as could be gained only by actual observation along the seashore! A collection of such records would be an orphanage, where the foundlings would doubtless be well cared for and thoroughly drilled in their little duties, and yet left without the inspiriting, enlarging influence of parental care that they find on adoption into the family of earth, moon, and sun.

Whatever the danger of schemes and theories, they give the best of life to our bodies of facts, and our science cannot survive without them. Indeed, we have come to know that the danger of systems and theories lies, not in their dependence on the imagination, but in the possibility of their careless growth and of their premature adoption, and even more in the acceptance of a personal responsibility for their maintenance, instead of leaving that responsibility to external evidence.

If there is any subject in which the aid of schemes and theories based on observations has been absolutely necessary for progress, it is earth science, where so many of the essential facts are invisible. It cannot be too carefully borne in mind that observation and theory are alike in their objects, however different they may be in their methods. Both seek to discover the facts of their science. One deals with facts that are visible to the outer eye; the other, with facts that cannot be seen, either because they are too small or too large for outer vision, or because they are hidden within the earth or in past time, or because they are impalpable abstractions or relations. In both, fancy is sometimes taken for fact, more often so perhaps in theorizing than in observing; but we must not for that reason give

up either means of investigation. We have learned that both observing and theorizing must be carefully conducted; and we have therefore replaced the earlier watchwords, "Go and see," with the later ones, "See and think." We may still give praise to those who apply themselves chiefly to gaining first-hand knowledge of observable facts, but we have learned to give greater praise to those who, on a good foundation of visible facts, employ a well-trained constructive imagination in building ingenious and successful theories which shall bring to sight the invisible facts. We have been longest familiar with the need of theory in those branches of our subject which have, by reason of association with mathematical problems, traditionally employed deductive methods in their discussion, as in earth-measurement; we are least familiar with it in those branches that have until lately followed for the most part inductive or even only empirical methods, as has so generally been the case with geography.

For example, in the study of the tides, already referred to, how unanimous we are as to the inadequacy of inductive methods; how universally we accept the marvelous theoretical scheme of interaction between planet and satellite, deduced from tidal theory; how we admire its extension to the supposed relation of the inferior planets to the sun! But in general geography, how little attention has been given to the deductive and systematic consideration of its many problems; how many geographers still look rather askance at those of their number who propose to treat geographical problems through theory as well as through observation! It seems to me clear that, while the earlier progress of geography was very largely inductive, the later progress has been largely determined by a free acceptance of deductive as well as of inductive methods, and that geography as well as geology is today profiting greatly from the use of our faculty of insight as well as of outsight.

The objections that are not infrequently urged against the employment of indirect, inferential, as well as of direct, observational, methods in certain branches of our science come from two sides. On one side is a misapprehension as to the nature of our tasks, a belief that our work may really be largely inductive, that observation alone will suffice, if patiently continued, to discover all pertinent facts. This is a serious mistake; there is everywhere more unseen than seen.

On the other side is the fear that theories may become our masters, and that we may appeal to them as infallible, and thus set ourselves up as authorities. This is a most natural induction from the history of our earlier progress, for we have repeatedly seen the sincere young investigator grow into the impatient old autocrat; it is a bit of human nature that we share with the rest of the world; it is analogous to the change of meaning in the word "tyrant," from a mere king to an arbitrary despot. But there is another verbal analogy in the change of the word "skeptic" from inquirer to doubter, and it is this analogy that we are now following. We have learned to doubt because we know we may be deceived; we mistrust careless eyes as well as careless thoughts, and insist that careful scrutiny be given to the work of both; we reduce the dangers of theorizing just as we reduce the errors of observing, not by avoiding that indispensable means of investigation, but by practicing it carefully, until we become experts in thinking as well as in seeing; and all this constitutes an important element in our recent progress.

In spite of what has already been gained by good theorizing, few realize how largely earth science, apparently a matter of observation, is really built up of inferences that go far beyond mere inductions. Many of the inferences have gained a certification so good and so familiar that in respect to verity they take rank with seen things, and we are apt to forget their origin. The successive deposition of bedded rocks, the organic origin of fossils, the original horizontality and continuity of folded and eroded strata—these inferences are today accepted as if they had never been doubted; but they all were once doubted, and they had to make their way against opposition. Whatever order of certainty they have now acquired, they are not facts of observation, but facts of inference; and, like the great body of earth science, these now well-accepted facts of past time have not been determined by direct seeing, but by inference on the basis of seeing. We may therefore justly claim great progress for earth science, not only in the extent and accuracy of our observations, but also in the extent and accuracy of our inferences. While there is yet need of more conscious recognition and more thorough training, especially in the deductive processes by which many problems may be solved, we may still say that among the most significant steps we

have taken in the past century are those by which the necessity and the value of theorizing have gained frank acceptance among investigators, and by which many of the results of theorizing have gained an order of verity that compares well with that of facts of mere observation.

An illustration of this phase of our progress is to be found in two definitions, each of which has a certain currency. By some writers, geology is defined as the study of the earth's crust, thus emphasizing the observational side of the subject; by others, geology is defined as the study of the earth's history, thus giving fuller recognition to the growth of inference upon observation. The second definition does not lessen the essential importance of observation as the foundation of knowledge, but it accords a proper value to inferences, and in this way is characteristic of what seems to me sound scientific progress. The earth's crust contains the incomplete, partly concealed, partly undecipherable records on which we are to construct the science of geology; just as human monuments and writings are the records on which we are to construct human history; but in neither case are the records and the history identical, for the history in both cases includes a great body of inferences as well as of more directly recorded or observed facts.

The wholesome appeal to observation in the search for visible facts has loosened the control of supposed authority and has given us much of the freedom necessary for progress; but the assistance of the trained imagination in the search for invisible facts has in a far greater degree corrected the assumptions of an earlier stage of inquiry; it has even revised the dicta of philosophy and remodeled the dogmas of religion.

The inferential element of our progress has worked most beneficently. It is largely through our inferences that we have come to recognize the interdependence of the different parts of earth science. The climatologist may remain as provincial as he wishes; or he may enter through the gateway of present conditions the vast domain of past time, and on the way make friends with all the world; for he will then join hands with the petrographer, who has evidence of ancient desert conditions in the form of the grains in certain sandstones; and with the paleontologist, who infers the existence of ancient ocean

currents from the drift of graptolite stems; and with the glaciologist, who is asking the astronomer and the physicist whether one or the other of them can best account for the Pleistocene ice-sheets.

Not only do the different parts of earth science thus connect with one another, but, as the last illustration showed, they interlace most interestingly with the branches of other sciences in the forest of knowledge. The systematist would, indeed, be at a loss to classify our work, if in classification he thought to keep it apart from other kinds of work. Better let it grow up naturally with interlacing tree-tops and crowded underbrush, each tree showing its individualized effort in the universal competition, than seek to trim it into an orchard of separate trees. The departments and sections into which we are divided in this congress do not represent objectively disconnected groups and units of knowledge, but associated parts in contiguous growths of acquisition; we must not hesitate to go out of conventional bounds and to trespass, as it is called, on other departments, when it is to our advantage. Others are surely free to do the same by us. When we employ methods called mathematical and physical in our study of the winds, the profit is not only found in direct results, but also in the use of deduction and experimentation, so familiar in mathematics and physics, and so much less practiced, yet so much needed in all parts of earth science; in return we supply data for the study of the phenomena of gases on the largest terrestrial scale.

We must be chemists, geometricians, and physicists in studying the minerals of the earth's crust; and in return we supply to the chemist a great variety of natural compounds, and to the physicist the material basis for a remarkable variety of optical phenomena. We must indeed marvel at the skill displayed by minerals—which invade, colonize, migrate, and settle again in the dark inner world—in handling external rays of light, and we may wonder if they have not had some preliminary practice on radiations of a kind that physicists have yet to describe. Admirable also are the crystalline forms that give realization to the early inventions of geometers, much in the way that planets and comets give us in their orbits great natural examples of the conic sections, familiar for centuries as mathematical abstractions.

But it is particularly with biology in all its branches that we have

learned to borrow and lend. The evolution of the earth and the evolution of organic forms are doctrines that have reinforced each other; the full meaning of both is gained only when one is seen to furnish the inorganic environment, and the other to exemplify the organic response. Without question, the interaction here discovered in the working of two great processes is the most notable discovery of the past century, not the less glorious because we share it with other sciences. For if they have to do with the players, we have to do with the scenery and the properties for the all-world stage, where the success of the players has been conditioned by our setting since the play began. In the universal habit of respiration as a means of gaining the energy by which all plants and animals do their life-work, we see a successful response to the presence of free oxygen, mixed in the air or dissolved in the waters, and hence we infer that free oxygen has been present in atmosphere and oceans, at least as long as life has existed on the earth. In the development of stem and root, of dorsal and ventral parts, we perceive the everlasting persistence of gravity; to fail in the recognition of this elementary example of interaction between life and environment would be on a par with neglect of the earth's rotation because the evidence of it is found in the commonplace consequences of sunrise and sunset.

The races of mankind, so inappropriately treated as a chapter of physical geography in many of our text-books, but really the prime factor of political geography, are obviously determined by the larger features of the lands; just as the development of the higher organic forms has been determined not on the monotonous ocean floors but on the lands, where variety has really been the very spice of life.

If we turn to history—not simply to the politics of the past, but to the real history of human thought and action—the progress of our own science furnishes innumerable examples of response to environing opportunity: how natural that the later geological series should have been first deciphered in England, where it is so well displayed; that the study of earthquakes and the invention of seismographs thrive in Italy and Japan; and that geomorphy advanced rapidly in our arid West through the study of the nude, just as sculpture flourished in Greece.

It is but the commonplace of economics to show the large depend-

ence of modern civilization on the occurrence of mineral deposits. Like the quiescent crystalline forces in the rounded quartz grains of ancient sandstones, still capable of determining the settlement of new molecules around the old ones, the marvelous stores of dormant energy and strength in beds of coal and iron ore have long bided their time. After ages of neglect, they have become the centers of great populations; and now that our princes of industry have through countless difficulties touched and awakened them to life, we find a new meaning in the old fairy story of the Sleeping Beauty.

Even those broader considerations that we meet in philosophy and religion have developed new phases as the schemes of earlier times have been modified in view of the geological record: the place of work in the world, not a curse, but a duty; the date of the golden age, not behind us, but ahead; the view of death, not a punishment, but a natural element in the progress of life; even the conception of immortality has come to be—with some—directed less to speculations about a continued life elsewhere than to the study of the continuity of life here.

Religious ideas themselves—at least when we examine them objectively in the beliefs of others than our own people—are seen as if in a mirror held to nature; and the very gods of the lower religions are but reflections of the powers of earth.

It is only when we consider these broad phases of earth science that we gain our share of profit from the revolution that replaces the teleological philosophy of the first half of the nineteenth century by the evolutionary philosophy of the latter half. Our conception of the earth as well as of its inhabitants has been profoundly modified by this revolution, and much of our progress has been conditioned on the full acceptance of the newer view.

Now, if apology is needed for introducing the preceding considerations, which some might call irrelevant, let me urge that whatever share they may make of other sciences, they are also so closely grafted into one or another branch of earth science that we, as geologists or geographers, cannot afford to neglect them. In so far as they are related to elements of our science as consequences are to causes, as responses are to environment, we must take at least some account of them, even if their study in other relations is left to specialists in

other subjects. In doing so, we are only carrying out our work to its legitimate conclusion. It is without question our responsibility to study the ancient inorganic conditions that determined the location and the migration, the development and the extinction of ancient faunas, for these conditions were at least in part geological factors of one kind or another; it is equally our responsibility to study the modern conditions that determine the location of cities and the routes of trade, for these conditions are largely geographical factors; but the examples of organic response here adduced are merely a few of many, and all the rest stand on an equal footing with them, whether they are commonly classed with biology or history, with economics or religion. We long ago saw that the more simple, immediate, and manifest examples of organic, especially of human, responses belonged in the realm of geography; and from this beginning we now realize that there is no stopping-place till we include all other examples, complex, indirect, or obscure as some of them may be; for there is a graded series of connecting examples from the most artful human response down to the most unconscious plant response, and from the immediate responses of today back to the earliest responses of the geological ages.

It would be most arbitrary to draw a division in our studies, when no division exists in the things studied. It is therefore a piece of good fortune that geographers are coming to follow the practice of geologists, and thus to accept among their responsibilities the great breadth of physiographic and ontographic relationships existing today, as geologists have accepted them for the past. And it is also as good fortune that biologists are coming to accept the responsibility of studying environment as well as response; for only in this way have the earth and its inhabitants really learned to know each other. I rejoice therefore whenever a student of earth science completes his studies by carrying them forward to their organic consequences, as seen from the side of the earth; and again, whenever a student of biology, of language, of economics, of religion, carries his studies backward to a consideration of inorganic causes, as seen from the side of life; for thus and thus only we may hope that the knowledge of both causes and consequences shall increase in fulness. Our present understanding of this interdependence, not only of different branches

of our own science, but of the branches of our own and of other sciences, is truly a great step toward the solution of the wonderful riddle of the world.

The real foundation of the broad consideration of earth science rests on the continuity of ordinary processes through the long periods of recorded earth-history. Nothing has so profoundly modified the appreciation of other subjects as well as of our own, as the teaching of geology concerning the conception of time and the long procession of orderly events that has marched through it. Such a conquest of the understanding is enough to make us proud indeed; yet when we realize how short a share of time has been allotted to us, how sincere should be our humility! Today we may be lords of creation, powerful through cephalization; yet in face of the repeated extinction of dominant races in geological history, how can we think otherwise than that we are clad only in a little brief authority; how can we seriously believe that we represent the highest stage, the acme of organic development, comforting and flattering as this deductive opinion may be!

The conception of the continuity of processes, without extra-natural interference, has been forced to fight its way against opposition; now it has gained at least a very general verbal acceptance among us, and is quietly drifting into popular belief. To realize its full meaning is an arduous task, not only because of the opposition of inherited prejudices, but even more because of the inherent difficulty of the problem. To think that processes such as those of today have done all the work of the past is appalling; yet we are constrained to believe it. Even as waves, beaten up in a stormy sea, subside after the winds are calmed, so the mountain waves or wrinkles of the earth's crust, growing as long as orogenic storms are at work, are in time calmed to plains; and this not by unusual processes, but by the patient weathering and washing of scraps and grains. While these slow changes go on in the extinction of mountain systems, the races of plants and animals that originally gained possession of the lofty young mountains, that grew up with them so to speak, must either adjust themselves to the changes in their surroundings, or migrate to other homes, or vanish, all in due order through the flowing current of time.

Nowhere is the orderliness of geological changes better attested than in the forms of ridge and valley seen today in various examples, young and old, of wasting mountain ranges themselves, and in the systematic adjustment that is attained by the drainage lines with respect to the structures on which they work. Here, indeed, is cumulative testimony for uniformitarianism; for nothing but the long persistence of ordinary processes can account for these marvelous commonplaces. So wonderful is the organization of these land and water forms in physiographic maturity and old age, so perfect is their systematic interdependence, that one must grudge the monopoly of the term "organism" for plants and animals, to the exclusion of well-organized forms of land and water. By good fortune, "evolution" is a term of broader meaning; we may share its use with the biologists; and we are glad to replace the violent revolutions of our predecessors with the quiet processes that evolution suggests.

It is the assurance of orderly continuity that binds the past to the present in the endless sequence of events, and shows us that geography is only today's issue of a perpetual journal, whose complete files constitute geology. He must be a geographer of the old school who would now maintain that his subject, in content and treatment, really belongs outside of the geological curriculum. It may, on the other hand, be justly contended that the whole of earth science is made up of geographic sheets—until today, paleogeographic, if you like—all horizontally stratified with respect to the vertical time line. In every sheet we find news of the relation of earth and life, of environing control and organic response, of physiography and ontography. Every little item of news here published is worthy of close attention. The reader may examine all sorts of items on a single sheet and consider their temporary, areal distribution, and so acquire the geographic view; or he may examine the changing items of certain areas, following their chronological sequence in successive sheets, and so acquire the geological view; but it would be unfortunate if, in so doing, he did not perceive the interchangeable relations of these two methods of investigation.

There is, to my understanding, a great profit that has been gained from conceiving the whole body of our science in the way thus suggested. Branches such as meteorology and terrestrial magnetism,

which we ordinarily treat as parts of physical geography and thus associate with present time, are seen really to have their ancient as well as their modern, their geologic as well as their geographic, phases. We can gain some hints as to ancient meteorology, for we find records of paleozoic raindrops, of remote glacial deposits, and we hope yet to find evidence concerning the distribution of early climatic zones. As far as ancient records of this kind can be pieced together, we may study them in their momentary or geographic, as well as in their continuous or geologic, relations. Concerning ancient phases of terrestrial magnetism we are at a loss; yet our conception of even this branch of earth science, as well as that of the meteorological branch, is certainly broadened when it is regarded as a contemporary of all the geological ages, and not merely as a latter-day characteristic of the globe.

Similarly, those geological events which we are accustomed to treat in their time sequence, gain fuller meaning when they are decomposed into their momentary elements, and when each element is treated as a geographical feature associated with its contemporary fellows. The columnar sections of stratified rocks, for example, so useful in the understanding of historical geology, are like the edgewise view of a closed book. The book must be opened, the leaves must be turned over one by one, the pages of these early records must be read, like so many gazetteers of ancient times. Never mind if some pages are worn and others are missing; those that can be still deciphered assure us that the past was generally like the present, and warrant the generalization that geology is like nothing so much as a whole series of geographies.

At the present stage of our progress, the sciences of the earth may be given a somewhat different classification from that of the eight sections into which they are divided for the purposes of this congress. These sections, as it seems to me, represent the subjective divisions of our sciences, within each of which specialists may limit their studies more or less closely, and for each of which speakers may be provided. But when regarded objectively, the divisions, their grouping, and their relative values, must be otherwise presented. Geology objectively considered is not merely one of the earth's sciences; it is the whole of them: it is the universal history of the earth.

It is true that geology has so largely to do with past time that it is not popularly understood to include the present; but it certainly does include the present, and the future also, as fast as it arrives. There is no possibility, in the understanding that we have now gained of earth science, of stopping the geological record at any stage of the Pleistocene, and calling the rest "geography;" that would involve the resurrection of buried theories, which held the past to be unlike the present order of things.

Conversely, geography is stultified when absolutely limited to the things of today, as if the things of the past were of another nature. It is of course popularly so considered, and perhaps for that reason its scientific development is stunted. When regarded objectively, the geography of today is nothing more nor less than a thin section at the top of geology, cut across the grain of time; and all the other thin sections are so much more like the geography of today than they are like anything else, that to call them by another name—except perhaps "paleogeography"—would be adding confusion to the earth's past history instead of bringing order out of it. Our plain duty here is to emphasize the continuity of events, that great result of our studies, and not to imply a break in their succession by using unlike terms for different members of a single series.

Geology thus being composed of a succession of countless geographies, geography, in its widest sense, is likewise composite, including its inorganic and its organic parts. It is particularly concerned with the surface of the earth today, as the home of life; but "surface" and "today" must here be very freely construed; for we must draw upon the sub- and super-surface parts, and on the days before today, whenever we find profit in so doing. When we study the shape and size of the earth, we touch upon what may be developed into geodesy. When we study the inorganic parts of the earth for themselves, in what may be called their static relations, we enter upon mineralogy and petrology, or geochemistry; for it must be remembered that water is a mineral and that air is a rock. When we study the dynamic relations of the inorganic parts of the earth, we have geophysics, within which oceanography and meteorology are subdivisions, of rank similar to terrestrial magnetism and to that large category of phenomena that includes the activities of the earth's crust. It is true

that physical or dynamical geology is the heading under which erosion, volcanoes, and earthquakes are usually treated, as if the present phenomena of the earth's crustal envelope were to be set aside from the present phenomena of the hydrosphere and atmosphere, and associated chiefly with the history of the past. But we have now certainly reached a point when the unity of all these subjects, their interaction in space, and their continuity through time demand their association in a single group of studies which shall embrace all the activities of the earth in their present manifestation; with the full understanding that the present is only the latest addition to the past, and that the past is only the integration of a vast series of ancient presents.

All these present physical activities, even if carried down to such specialties as potamology and kumatology, are so closely associated with the standard subjects of geography that it is difficult and unadvisable to cut them asunder. Yet every one of them may be carried to such a degree of detail as to stand apart, and gain rank as an independent study. The accuracy of the geodesist, the minuteness of the mineralogist, the high flights of the meteorologist have now gone so far in their special development as to lead far away from each other, when they are studied for themselves, however closely their more general results may be associated.

When, however, we study the inorganic features of the earth, not as independent phenomena, but as elements of organic environment, they all belong strictly in physical geography, or physiography. Parenthetically, let me say that I regret the excessive breadth given to this term by British students, and the narrowness imposed upon it by those Americans who would limit it to the study of the lands. When we pursue the subdivisions of physiography, nomenclature becomes incomplete: climatology is unique in being a name for the study of the atmosphere in so far as it determines organic environment; economic geology is a study of useful minerals and rocks, but is less strictly treated as an objective subdivision of physiography than is climatology; and there is associated with it so much of ingenious artifice in the exploitation and treatment of mineral products that we are apt to put the cart before the horse and think that we make gold or coal serve our needs, instead of realizing that we make ingenious

use in money and fuel of the properties that gold and coal possess, just as we make use of moving air in wind-mills and of falling water in factories.

There are no special names for the phenomena of oceans or of the other divisions of physiography, considered as elements of organic environment; and there is perhaps no need of such names. Yet I hold that it is desirable, and even important, to recognize the two ways in which the inorganic features of the earth may be studied: either for themselves, without regard to their controls over organic life; or as elements of an inhabited planet, with continuous attention to the controls that they exert over the inhabitants.

When we come to the organic inhabitants of the earth, it is evident that they fall under biology when studied for themselves, and that they may be divided under botany and zoölogy, and subdivided as often as is desired. This is manifestly true as well of fossils as of living forms. When, on the other hand, the inhabitants of the earth are studied with respect to the responses that they have made to their inorganic or physiographic environment, they are appropriately included under geography. It has been recognized for many years that no geographical description of a region is complete without some account of its plants and animals, and especially of its peoples; just as no paleogeographic account of a geological horizon would be satisfying if its fossil fauna and flora were left unmentioned. But in recent years it has been seen necessary to treat uniformly all the organic elements of geographical descriptions in their relations to environing controls; for, as I have already shown, if a beginning is made, there is no reasonable stopping-place until this end is reached.

We are in this matter still sometimes too much under the control of traditional methods of treatment; we do not fully enough put into practical effect the greater lessons that we have learned. The earth as the home of man is a primitive, elementary definition of geography; the earth as the home of life is more consistent with present progress. Earth science has now certainly reached a position in which the unity and continuity of life are recognized. Let us then adopt this position as our starting-point in the organic half of geography that may be called ontography. Let us make it practically useful by treating all organic responses to environment under one general heading,

even though we afterward find it desirable to treat human responses in a separate chapter. For even if man's will sets him high above the other forms of life, it must not be forgotten that his will often leads him along physiographic lines, and that he possesses many structures and habits entirely independent of his will, and similar to the structures and habits of lower animals as examples of ontographic responses. Even human houses and roads are only different in degree from the houses and roads made by animals of many kinds. Still more, if we accept the principle of the continuity of geography through geology, we must recognize that most of the successive geographies of the past have had nothing to do with the human will, and that man and his works are after all only modern innovations.

The chief impediment to action upon this view, which, as I have said, has been unfolded before us by the progress that our science has already made, is the habit of studying geography and geology too separately, and of regarding the former as a subject for narrative treatment, while the latter is admittedly a subject for scientific investigation. The hint to this effect that is given by the unlike constitution of geographical and geological societies the world over ought not to pass unnoticed. Membership in many geological societies is limited to experts; if membership in a single geographical society is similarly restricted, I have yet to learn of it.

Let us then build on the progress we have made; let us realize that only when ontography is treated as thoroughly as physiography will geographical work gain the best geographical flavor. So empirical has been the traditional geographical treatment of the organic elements, so imperfectly have the organic elements been generally recognized as balancing the inorganic elements in the make-up of the subject as a whole, that no name has come into use for the organic half of geography corresponding to physiography for the inorganic half; and it is to supply this lack that I have elsewhere suggested the name above used. I believe that the adoption of some such name would aid in the systematic cultivation and in the symmetrical development of geography, and thus of geology also as a whole, by bringing more prominently forward the necessity of giving—or at least attempting to give—as scientific a treatment to the inhabitants of a region in their geographic relations as to the region itself.

The adoption of some such term as "ontography" would tend to correct the false idea that geography is concerned only with the elementary and manifest examples of organic responses; it would promote thoroughness of study, and thus more fully continue the progress that we have thus far made. The adoption of the term would, moreover, emphasize the principle of continuity through time—of the geographical stratification of geology, which is of so great importance in the scientific development of our subject; for ontography, in which persistent physiographic influences make themselves felt through inheritance, is then seen to be only the modern member of a great series with whose earlier members we have long been familiar in paleontology. The recognition of the continuity, the essential unity of these two subjects—one dealing with the living forms of today, the other with the dead forms of the past—dignifies the first and vivifies the second; and adds yet another argument in favor of an objective rather than a subjective classification of the sciences of the earth. The beginning of the cultivation of ontography, already made more or less consciously, strongly suggests a larger development for the future. We are thus assured that as the details of organic responses are worked out and the importance of physiographic details is recognized, the difference between physiography as the study of environment, and geochemistry and geophysics as the study of the earth for itself, will diminish. Today no one can say how far the details of these semi-independent sciences may not be found essential in physiography.

Let me now amuse you for a moment with a scheme of terminology that might have a little value if some of its terms were not already appropriated in other meanings. The scheme does not represent the historical development of earth science, but sets forth its several parts in the relations that our progress up to date shows them to stand.

Suppose we should use the ending *-ology* to denote the conception of sequence in time, and *-ography* to denote the conception of temporary distribution. We should then have our whole subject, geology, in which time sequence is the dominant idea, made up, like an endless prism of mica, of an indefinite number of momentary sheets of geography that cleave across the time axis. Biography would then lose its

limitation to man, and become the study of temporary floras and faunas in successive geographies; while biology would give up its usual meaning and become the study of life in the developmental sequence of organic evolution through geological time. The study of the minerals and rocks of any epoch would be minerography and petrography, while mineralogy and petrology would treat problems of paragenesis and metamorphism in which the passage of time is essential; and for one, I should then be able to remember what petrography and petrology mean. So we might go on with physiology, meteorology, and oceanology as made up of a succession of physiographies, meteorographies, and oceanographies, and we should have glaciology and climatology made up of glaciography and climatography; and ontology or the sequence of organic responses to the changing earth, would be made up of a succession of ontographies.

Schemes of terminology, however, are not often successfully made to order in this fashion; they are slowly evolved without much regard to system, as is seen in the haphazard nomenclature of oceans, seas, gulfs, and bays. Minerography is strange to the point of offense to the ear; we cannot take over biography and physiology from their present uses; we must get along with the terms that we have, and with such new ones as are added from time to time. My only object in suggesting this fanciful scheme is to bring more clearly forward the space- and time-relations that are recognizable in all branches of our subject, as well as in geography and geology. The progress of the last century has certainly brought us now to a stage when these general relationships may be in good part understood, if we give heed to them. We fail to take the best advantage of our progress if we see only the specialized development of our several subsciences.

It has often seemed to me as if petrologists were rather overwhelmed at present with the flood of new facts that modern methods of research have let loose upon them; yet how greatly is the study of both mineralogy and petrography broadened by the addition of the continuous to the momentary consideration of minerals and rocks that the flood has swept before us; for even the rocks have their phases of youth and age. So brief is our life that geomorphologists are even today hardly accustomed to the systematic mobilization of land forms; yet the description of the lands is greatly strengthened when their forms

are seen to be fixed only in the sense that an express train seems to be fixed before the instantaneous wink of a camera's eye. The ontographer may be bewildered when he realizes what the evolutionary struggle for existence means to the individual; and when he thinks how long the world was the scene of relentless strife before pity was born, and how young and impotent pity is still, we may well wonder whether we have yet learned much of omnipotence. Yet how superb is the conception of the procession of life, never halting in its march through the corridors of time.

The addresses of the eight sections into which the department of earth science is divided will so fully consider the special problems with which we are concerned that it has seemed best here to deal only with a few general considerations. I have therefore sought to consider only the prospect from the point of view to which the progress of a hundred years has led us. Vast as is the expanse over which we look, innumerable as are the elements of the view, the chief impression that we gain is one of well-ordered interaction in the continuous progress of events, all of whose momentary geographic phases, with all their parts of earth, air, water, and responding life, are spread upon successive pages in the great volume of geological records.

W. M. DAVIS.

CAMBRIDGE, MASS.

NOTICE OF SOME NEW REPTILES FROM THE UPPER TRIAS OF WYOMING.

THE University of Chicago paleontological expedition to Wyoming the past summer was fortunate in securing a valuable collection of stegocephalian and reptilian remains from the Trias, a part of which is described in the present paper.

The beds whence the fossils were obtained, from forty to eighty feet in thickness, are about two hundred feet below the top of the red-beds and about six hundred feet above their base. Their description will be given in a later paper by Mr. N. H. Brown, their discoverer, and the writer. Meanwhile the horizon may be distinguished by the name Popo Agie[1] beds, as suggested by Mr. Brown, from the Popo Agie River, along whose branches they are most characteristically shown.

Dolichobrachium gracile, gen. et sp. nov.

Coraco-scapula (Fig. 1).—Scapula elongate, flattened, directed backward nearly parallel with the long axis of the body; the blade elongate, moderately thickened, and of nearly equal width throughout; back of the middle of the lower margin, there is a slight angular projection. Anteriorly the bone curves sharply downward to the glenoid fossa, at right angles to the shaft, and has a free, thin, rounded margin in front. The upper margin of the glenoid fossa is thick, prominent, and rounded, supported by a strong thickening of the bone above it; in front this thickening has a heavy, rounded margin standing out prominently from the thinned anterior plate of the scapula. The fossa has no rim in front, the surface blending into the non-articular sloping surface extending to the thin front margin of the bone. Nor is there a rim behind, but below the border is very prominent, more so than the upper border, though thinner, the bone being excavated below it to form an obliquely projecting rim. Coracoid elongate antero-posteriorly, the anterior part directed strongly inward; the posterior margin nearly on the same plane as the glenoid fossa and

[1] Pronounced *popo azhie*, or, in the vernacular, *popózhie*.

the inferior border of the shaft of the scapula. The anterior part of the coracoid, though preserved, has not yet been fitted to the remainder of the bone; it is rather thick, and seems to have been directed strongly inward. No traces of a supracoracoid foramen, nor of any connecting sutures are visible in the united bones.

Humerus (Fig. 2).—The left humerus, found associated with its corresponding coraco-scapula, is a remarkable bone. The head is thickened, the shaft curved forward and compressed, the condyles have a long articular sweep and are obliquely placed. The dorsal surface proximally is convex from side to side below the slightly prominent head, the lateral or deltoid process forming a long, backwardly curved margin. On the palmar side the surface is concave, and the head is more prominent, the slightly convex articular surface looking mesad and ventrad.

FIG. 1.—Left coraco-scapula of *Dolichobrachium gracile*.

The shaft, distad to the lower end of the deltoid process, is strongly compressed from side to side, with a considerable convexity in front. The condyles stand far backward, the inner one more prominent and slightly longer than the outer one. They are also obliquely placed, so that, when resting on a plane, the plane of the upper part is not more than thirty degrees from the vertical.

The external condyle extends through nearly three-fourths of a circle; the trochlear groove is deep and narrow. On the outer side, a little above the end, there is a thickened, rounded projection, partially separated from the shaft by a groove; it perhaps corresponds to the supinator ridge. The bone has no internal cavity.

In addition to the bones described above, the specimen as collected comprises a number of ventral ribs and a large part, perhaps the larger part, of the skull. The latter, however, is badly shattered from exposure, and will require much patient labor to restore it. In much probability other bones of the skeleton remain to be excavated, and it is hoped to secure them the coming summer.

FIG. 2.— Left humerus of *Dolichobrachium gracile*.

The specimen was discovered by Mr. Roy Moodie and Mr. E. E. Ball.

What the relations of this animal are it is at present impossible to say, other than it probably belongs to the early rhynchocephaloid type, or in the super-order Diaptosauria of Osborn. I can find nothing in the literature, of either the Permian or Triassic reptiles of Europe or America, which approaches it. The structure of the girdle, the shape of the humerus, and its mode of articulation indicate a swift-moving crawling reptile of considerable size. The skull will doubtless throw much light on the affinities and habits of the animal. I hope to present a discussion of this part of the skeleton within a few months.

Height of glenoid fossa	120 mm
Antero-posterior extent of same	102
Width of coracoid below rim of glenoid fossa	120
Width of scapula above rim of glenoid	152
Antero-posterior expanse of scapula	460
Width of blade of scapula	108
Length of humerus	445
Greatest width, upper end	147
Width of shaft, lower third	44

Eubrachiosaurus browni, gen. et sp. nov.

Left humerus (Fig. 3).—Head, when seen from above, elongate oval or semilunate, the posterior border strongly convex. Tuberosity (median process of Fürbringer, teretial process of Owen) separated by a narrow and constricted depression from the capitular

border; expanded below, the gently convex surface looking ventrad and mesad, extending a little less than a third of the length of the bone. Below this process, on the inner border, there is a small convexity, which may, perhaps, represent the tricipital process. Inner ventral surface above deeply concave; bounded above and on the side by the margin of the capitular projection and that of the median process. Lateral (deltopectoral) crest elongate and thickened, very protuberant, extending a little more than one-half the length of the bone (ten inches), directed obliquely outward and ventrad; outer margin convex, but produced into an obtuse angle below, the thickness somewhat greater below. In the specimen this process has been slightly crushed dorsad. Posterior surface proximally gently convex, concave on the outer side, with the rounded head strongly protuberant. Shaft below lateral crest much constricted, its conjugate diameters being nearly equal. Entepicondylar canal directed nearly downward, the flattened bridge over it being the continuation of the lower margin of the lateral crest. Entepicondyle thickened and roughened for muscular attachment; ectepicondylar or supinator ridge broad, arising as high up as the upper margin of the external opening of the epicondylar canal, and nearly as high as the lower end of the lateral crest, its border nearly semicircular in outline, gently curved forward. Olecranal fossa large, shallow, triangular, nearly flat. Radial articular capitular surface large, convex, forming a small, rounded process on the dorsal side and a large one on the ventral side. Ulnar articular surface smaller, but extending nearly as far ventrad, the intervening trochlear groove rather deep and narrow.

FIG. 3.— Left humerus of *Eubrachiosaurus browni*.

Scapula.—An elongate bone, presenting the essential characteristics of a dicynodont scapula, was found lying with its distal end impressed upon the inner side of the ilium, and close by the humerus

above described. Its size and slenderness seem disproportionate to the massiveness of the humerus, but that it belongs with the pelvis and humerus there can be scarcely a shadow of doubt. It has a thickened articular end below, a part of which is missing—that which protruded from the face of the cliff and led to the discovery of the specimen. Doubtless there was another facet here for the coracoid. The upper part is expanded and flattened, with the anterior border thickened, the inner surface somewhat concave. This thickened anterior part is continued into an elevated ridge on the dorsal side, which ends rather abruptly near the lower extremity—the acromion.

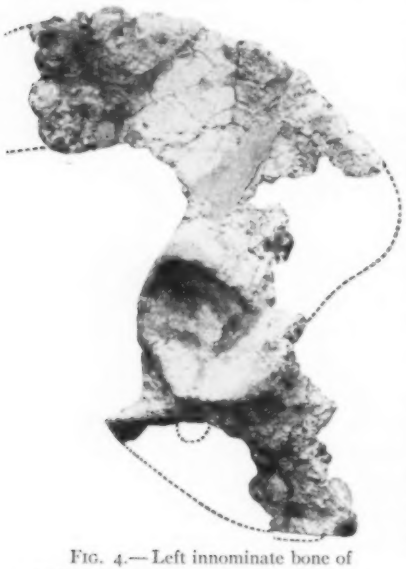

FIG. 4.—Left innominate bone of *Eubrachiosaurus browni*.

Pelvis (Fig. 4).—The bones which, because of their shape, must belong to the left side of the pelvis, from the position in which they were found and from certain peculiarities of their shape, were first thought to belong with the pectoral girdle, and it was not until the specimen had been nearly completely reconstructed that its real nature was apparent. The most remarkably dilated and elongated anterior part of the ilium, had it not been so strongly curved, would rather represent the blade of the scapula, and no articular surfaces for the attachment of the sacral ribs have been detected—there are certainly none such low down on the bone.

The united ischium and pubis were slightly separated from the ilium on the left side, and entirely so on the right side. The connecting surfaces were so incrusted with the tenaciously adhering matrix that their sutural nature is not apparent, though without doubt the separation took place at the suture, since the united ischium and pubis of the opposite side have the same shape.

The ilium extends upward and forward in a broad curve. The upper portion is broad, flat, and rather thin. The distal part had been broken off before fossilization, and the attaching fracture so corroded and incrusted with matrix, removable with difficulty from the thin bone, that its precise relations are somewhat doubtful. This portion has been omitted in the photograph, but the free, thin, concave border seems to continue the curve before it for about eight inches, the distal portion being somewhat dilated and very thin. Such a shape is most extraordinary for an ilium. This part of the ilium turns outward as though for the protection of the abdominal walls. The posterior border of the ilium was unfortunately lost before the presence of the bone was suspected, lying as it did below the scapula. It was evidently thin.

The acetabulum forms a deep oval cavity, somewhat notched at the upper posterior part. The pubis was directed obliquely inward, and has a strong, everted, articular face, perhaps for an epipubis or prepubis, very much as has been figured in species of dicynodonts.[1] A little in front of the middle, and about two inches below the rim of the acetabulum, there is seen a short, free margin, evidently the upper margin of the thyroid (obturator) foramen, and in all probability situated in the line of the suture between the pubis and ischium, since both bones were broken apart in this same place. The border connecting the pubic and ischiadic angles has not yet been reconstructed, but patient labor will doubtless fit in the whole of this portion from the many thin fragments preserved in each of the specimens.

The pubis and ischium are turned inward toward the median line.

Lying upon the distal part of the humerus there was a small bone, about six inches in length, which seems to be a sacral rib, resembling as it does the corresponding bones of some dinosaurs.

Length of humerus	440 mm
Greatest width across lateral process	237
Breadth, lower end of lateral process	182
Least diameter of shaft	68
Greatest width, distal end	263

[1] *Tapinocephalus*, Lydekker, *Catalogue of Fossil Reptiles*, British Museum, IV, 82.

Length of scapula	444
Least width, a little above acromion process	63
Greatest width	213
Thickness of glenoid articulation	55
Height of ilium	650
Diameters of glenoid fossa	140, 160
Expanse of ischio-pubis	320
Length of pubis from rim of acetabulum	145
Length of ischium from rim of acetabulum	200
Width of blade of ilium	170

The specimen above described was found protruding from a face of the cliff near the uppermost part of the Popo Agie beds, in the vicinity of the Little Popo Agie River, by Mr. Roy Moodie and the writer. The specimen was partly worked out by myself, and later by Mr. Branson and Mr. Moodie. The great difficulties under which the specimen was secured prevented at the time exploration for other bones. There can be little doubt but that other parts of the skeleton, perhaps the larger portion, still remain in the rocks, and, it is hoped, will be secured another season.

What the relations of *Eubrachiosaurus* are with other reptiles it is yet impossible to say with much degree of certainty. I do not believe that the genus belongs with the Pareiasauria, chiefly because of the presence of an entepicondylar foramen, though the humerus resembles that of *Pareiasaurus* somewhat. The humerus recalls that of *Platypodosaurus*, but, upon the whole, I believe that the animal will be found to be nearest related to *Tapinocephalus* or *Phocosaurus*, from the Karoo beds of South Africa. The ilium is incompletely known in these genera, but the size of the acetabulum, the shape and structure of the ischio-pubis, the posterior projection of the ilium and the limited sacral attachment, all point to that genus. At all events, I believe that the genus, as also *Placerias* Lucas, and the following, belong among the true Anomodontia. From *Placerias* Lucas,[1] from the Trias of Arizona, this form differs very evidently in the great expansion of the lower end, the ectepicondyle, which is figured in *Placerias* as convex and thick, being widely expanded.

Brachybrachium brevipes, gen. et sp. nov.

A single humerus, though incomplete, found near the upper part of the Popo Agie beds, and in almost identically the same horizon as

[1] *Proceedings of the U. S. National Museum*, 1904, p. 194.

that of the preceding genus, shows such decided differences, and, moreover, is so characteristic, that I venture to describe and name it. The upper extremity is thin and narrow; probably some portion of this had been lost prior to fossilization, but inasmuch as Broom describes this extremity in *Udenodon* as narrow, I believe that little is missing. The thick and massive lateral process is directed upward. The inner condyle is rounded below, showing that nearly the whole length of the bone is present, though the outer condyle, that projecting from the face of the cliff, is wanting. The large entepicondylar canal begins considerably above the lower angle of the lateral process, and not wholly below the process, as in *Eubrachiosaurus*. The bridge covering it is very stout. The median process is small, not protuberant and flattened, as in the last genus. The outer border is concave from above downward, strongly convex transversely. At the lower end of the part preserved the border becomes thinner, but it is not possible that there was any such supinator expansion as is shown in *Eubrachiosaurus;* if any, it was situated much more distad. The condyles must have been remarkably broad, equal to much more than half the length of the bone, and the olecranal fossa is large and deep. The upper part of the palmar surface of the ulnar process is preserved, and is much more massive and prominent than in *Eubrachiosaurus*. If the radial prominence was relatively as large, it must have been very massive.

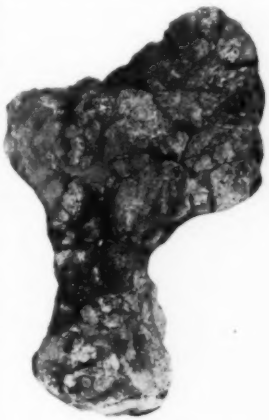

FIG. 5.—Left humerus of *Brachybrachium brevipes*.

The specimen was discovered by Mr. Roy Moodie, and removed from the very hard sandstone by him and the writer.

Length of the bone as preserved	255 mm
Width across lateral process	197
Estimated width of condyles	200
Least diameter of shaft in plane of condyles	70

Paleorhinus bransoni, gen. et sp. nov.

(Fig. 6).—A new genus of phytosaurs, somewhat more primitive than any hitherto made known, though agreeing rather better with *Belodon* than *Phytosaurus*, is represented in the collection by a nearly perfect skull in excellent condition. The genus is especially characterized by the more anterior position of the external nares, their nonseparation by the nasal bones, and by the more lateral position of the orbits. The accompanying outline figure of the side of the specimen will show the positions of the various openings better than they can be described. Some of the sutures have not yet been determined. The external nares are at the extremity of a nose-like protuberance, the openings looking partly upward, partly forward

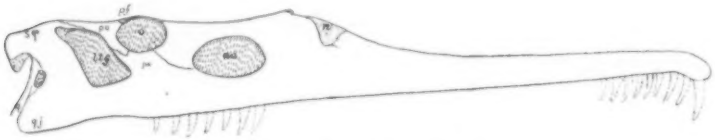

FIG. 6.—Skull of *Paleorhinus bransoni*.

and outward, separated by two, thin, vertical plates, perhaps the mesethmoids. The ontorbital opening is elongate oval in shape, and situated between the orbits and nares. The anterior part of the beak is turned downward, as in *Phytosaurus*, and has a single large tooth on each side. The posterior end of the mandible is shaped much as it is figured in *Mystriosuchus* by Fraas, that is with a very small angular projection situated low down. The front end of the mandible is missing.

Length of skull	735 mm
Length from tip of beak to nares	390
Length to front end of orbits	565
Width between orbits	42
Width of skull posteriorly (about)	190

From *Typothorax* Cope and *Episcoposaurus* Cope, based upon fragments, the form is evidently different. From *Heterodontosuchus* Lucas, from the Trias of Utah, based upon the anterior end of the mandible, I cannot state the differences with assurance. The only available character given for that genus is the proximity of the

teeth, since all the teeth had fallen from the sockets in this specimen. The teeth are not separated by an extremely thin partition, but have quite an interval between them, in some cases equal to the diameter of the sockets. I feel more confidence in the distinction, however, from the fact that another genus in the collection has the teeth much more closely placed.

Another form, represented by a complete skull of larger size, in the collection, has the anterior nares apparently placed much further forward than in the present genus, or at least the beginning of the slender beak is much further forward. Yet another skull, of large size and nearly complete, has been nearly freed from its matrix. It measures 960 mm in length; the nares are not as far forward as is the front end of the ontorbital opening, though more anteriorly placed than in *B. scolopax* Cope, and the strongly deflected anterior end of the beak has three large teeth on each side. The hind teeth are flattened and serrate. Still another skull seems different from any of the foregoing.

S. W. WILLISTON.

PLEISTOCENE GEOLOGY OF THE SAWATCH RANGE, NEAR LEADVILLE, COLO.

THE writers, as students of geology in the University of Chicago, spent two months of the past summer in studying the glacial geology about Leadville, Colo. It is their plan to continue the work next summer. The work was carried on under the direction of Professor R. D. Salisbury, who was with the writers for a week toward the close of the season's work.

So far as known, little detailed work on the Pleistocene geology of the region had been done. The maps of the Hayden Survey mark certain areas as being morainic, and Mr. S. F. Emmons, in his monograph,[1] mentions briefly the effects of glaciation in this area; but otherwise little seems to have been published.

The work of the past summer was mainly on the east slope of the Sawatch Range. It covered all the area on the Leadville quadrangle of the U. S. Geological Survey, which lay to the west of the Arkansas River, the Tennessee Fork, and the Eagle River.

TOPOGRAPHY

The chief topographic features of the region are the two great parallel north-south mountain ranges, the Sawatch Range on the west, and the Park Range on the east. The higher peaks of both rise to heights of more than 14,000 feet. In the trough between these ranges are the Arkansas and Eagle Rivers. The former flows south, and the latter north. These rivers are fed by large numbers of tributaries from the slopes to the east and west, most of the tributary valleys being almost at right angles to the valley of the main stream.

GLACIATION

The area studied is about 350 square miles in extent. Of this, 275 square miles show definite effects of glaciation. It is probable that, at the maximum, the ice covered a somewhat larger area. The drift is referable to at least two distinct epochs of markedly different

[1] *Monograph XV*, U. S. Geological Survey, pp. 41–44.

age, with possibilities of a third epoch much earlier than the two whose results are well marked.

EXTENT OF ICE

The last glacial epoch.—The ice of the last glacial epoch covers by far the larger part of the surface of the mountains proper. The ice came down all the larger valleys tributary to the main valley, and in most cases only the narrow crests of the ridges between the side valleys projected above the glaciers. In several instances the glaciers of the side valleys descended to the present position of the river in the main valley, and in a few cases they crossed the main valley to the base of the opposing range. Of the entire area west of the great north and south valley about three-fourths was covered by the ice of the last glacial epoch, and a large part of the unglaciated one-fourth lies beyond the foot of the mountains proper.

Ten distinct systems of glaciers of some importance were studied in this area, besides four cliff glaciers of small size. Of the ten more important systems three extended barely to the foot of the mountains. Seven got well out into the wide valley, east of the mountains, and five of them extended to the present position of the river, and the same number extended below the 9,000-foot contour.

The glaciers varied in length from one to twenty miles, and in area from one-third of a square mile to about eighty square miles. The Lake Creek system was longest, and also greatest in area. Of the very small glaciers, one started at an elevation of 11,000 feet, but an elevation of about 12,000 feet seems to have been necessary to start glaciation in most places. The glaciers all originated in similar situations. Their sources were in cirques which lay back toward the higher parts of the mountains. The ice from these cirques, moving downward, merged in each of the principal mountain valleys, and developed a tongue of ice which advanced far down the valleys. About sixty separate cirques contributed to the ten large glaciers of the region.

In all the larger glaciers the ice had a thickness of over 1,000 feet, while in the valleys of Homestake and Roche Moutonnée Creeks the thickness exceeded 2,000 feet.

The drift.—The character of the glacial deposits varies greatly in

topographic form and physical constitution, with the character of the surface upon which the deposits were laid down, and with the material which the ice had to handle. In the Evergreen Lakes glacier, for example, the drift has a characteristically new appearance, both in respect to its materials and its topography. The material of the drift of the Lake Fork glacier, on the other hand, looks very old. There are few large bowlders at the surface, and most of the rock material in the drift is notably decayed. But the topography of even this moraine is new, and it was, without question, contemporaneous with the newer appearing drift of the Evergreen Lakes moraines.

The difference in the material in these two cases is to be explained by the difference in the condition of the rocks over which the two glaciers moved. Even now the bed-rock in the upper part of the valley of Lake Fork is deeply decayed, showing that the glacier did not clean out even all the decayed rock. The upper part of the area out of which the Evergreen Lakes glacier moved is of hard fresh rock, showing that the ice of the glacier removed not only all decayed rock, but also some of the fresh rock beneath. The freshness of the drift deposited by this glacier shows that much undecayed rock was worn away by the ice.

The glaciers terminated in two classes of situations, and their terminal deposits stand in a somewhat definite relation to the position of the ends of the glacier. The ice in the valleys of Homestake and Rock Creeks, and in the valley west of Mitchell, never reached a Piedmont plain upon which they could deploy, but ended in the narrow mountain valleys. Under these conditions there was no opportunity for the terminal deposits to accumulate in great terminal moraines, since the abundant water from the melting ice carried the drift away about as fast as the ice left it. No terminal moraines of consequence occur at the ends of these glaciers.

The other larger glaciers of this region sent their ice beyond the confines of the narrow valleys, and deployed to some extent on the valley plain beyond, building great terminal moraines. These two types of termini and of terminal accumulations are well shown by the glaciers of Homestake Creek, on the one hand, and those of Lake Fork, Clear Creek, and Half Moon Creek, on the other. The absence

of terminal moraines in the former case has been noted. In glaciers of the Lake Fork type, the ice deployed on the plain at the base of the mountains, and enormous quantities of drift were piled up in the form of terminal moraines. The terminal moraines often have abrupt outer faces, 200 to 300 feet high, and are marked by a characteristically irregular, hummocky topography.

The terminal moraines are continuous with and merge into the lateral moraines in the mountain valleys. The lateral moraines are often large and lie against the valley walls, their crests sloping down the valley. The crests of the lateral moraines are over 700 feet above the stream in some parts of the valley of Clear Creek, and descend with an even slope of 200 to 400 feet a mile down the valley. Beyond the mountains, the lateral moraines tend to flatten out, and merge into extensive terminal moraines.

Little detailed work was done on the glaciation of the Park Range, but it is known that ice of the last glacial epoch occurred in the "gulches" east and southeast of Leadville; in the valleys of the East Fork of the Arkansas River, Ten-mile Creek, and over a considerable portion of the east slope of the Park Range.

The older drift.—In a number of places within the area studied there are tracts covered with scattered bowlders or bodies of drift, which are certainly of glacial origin, but which are much older than the drift of the last ice epoch. In these patches the present topography is due to erosion, all signs of kettles, or irregular hummocks, having disappeared. The rock outcrops have generally been weathered into sharp crags, a change which certainly required much more time than has elapsed since the last glacial epoch. The surface bowlders, too, are often weathered considerably, crumbling to pieces under the hammer.

The evidence that this drift is glacial is found along several lines. The bowlders are of a size which would militate against a fluvial origin. Striæ are sometimes found on the under, unweathered surfaces of the bowlders, or on the faces of those in fresh cuts in the drift. The distribution is such as would be expected from older and more extensive glaciers, for the drift in question occurs just outside the new drift, or above it on benches to which the last ice did not reach. The patchiness of the old drift is due largely to

erosion since its deposition. In one or two instances the older drift shows something of the lateral moraine ridge form, outside and above the newer lateral moraines, but more often it occurs in thin sheets, or merely as scattered bowlders.

Possibility of a still earlier epoch of glaciation.—Certain facts point to the possibility of a still earlier epoch of glaciation in this region. Two miles above Granite, on the east side of the Arkansas River, bowlders were found 200 feet above the river, which seem to have come from the Sawatch Mountains. These bowlders are rather rare, and are much weathered, although of very resistant granite.[1] The position of these bowlders beyond the limits of the ice of both well-determined epochs of glaciation points to a possible

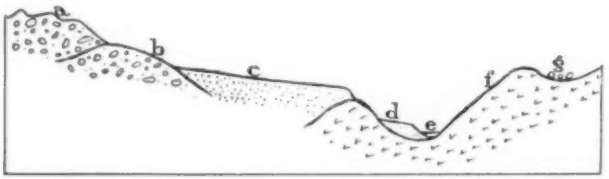

FIG. 1.—A generalized section across the valley of the Arkansas, to illustrate the conditions in the vicinity of Granite.

a, terminal moraine of last epoch from a side valley; *b*, moraine of older drift; *c*, high terrace lying against older drift; *d*, low terrace corresponding in age to *a*; *e*, Arkansas River; *f*, granite into which river has cut a post-older glacial channel; *g*, bowlders from mountains on opposite side of valley, which appear to be older than *b*.

period of glaciation older than either, the drift of which has been almost entirely removed. The evidence, however, does not seem to be altogether conclusive. Some other bits of evidence of like import are found at other points, but they have not been sufficiently developed to make their significance certain.

The general relations of the two sheets of drift to each other, and of both to the valley gravels, and to the scattered bowlders of still greater age, are shown in Fig. 1.

TERRACES

High terraces.—A most striking feature of this region is the great display of terraces, seen at their best on the east side of the Arkansas River, south of Leadville. These terraces rise with abrupt faces

[1] These bowlders were found by Mr. L. F. Westgate, before the writers visited this side of the valley.

above the river flat, and slope upward toward the base of the mountain at an angle of 2–4°. They have plane surfaces and uniform slopes, and, although deeply cut by erosion, are evidently remnants of a plain which sloped somewhat continuously from the base of the mountains on either side of the valley to an axial trough somewhere near the middle of the valley.

In constitution these terraces are composed of well-rounded, water-worn gravels, coarser toward the base of the mountains and up the Arkansas valley, and finer away from the mountains and down the valley. In general, the gravels in any particular place seem to correspond to the rocks found in the mountains just above. For the most part these beds are uncemented, although locally the gravels have been cemented into a friable conglomerate by lime carbonate.

Mr. Emmons, in his monograph on the Leadville district,[1] refers to the terrace deposits as being of lacustrine origin, and argues that the slope of the terraces away from the mountains is due to subsequent tilting. The correspondence in the slope of the terraces on the two sides of the valley, and the lack of any observed deformation in the beds, do not seem to favor the view that the beds have been tilted since deposition, while the coarseness and the imperfect stratification of the gravels, and the absence of any observable delta stuctures, seems to the writers to make the Lake Bed hypothesis untenable. Although locally there may have been small lakes in which deposits of gravel were laid down, by far the greatest portion of these deposits are referable to river work. With this hypothesis the slope of the terraces is in harmony. These deposits must at one time have been considerably more extensive than now, for the Arkansas River has cut a very considerable valley in the former plain of aggradation.

For the construction of the plains from which these terraces were developed there must have been a great amount of detritus supplied to the streams. In following the high terraces from the river to the mountains on either side we found in the three places which were most carefully studied, that their upper edges were in contact with bodies of older drift. The earlier glaciers, of considerably greater size than the later ones, may have supplied great quantities of débris to the

[1] *Monograph XII*, U. S. Geological Survey, pp. 41, 71, 72.

swollen streams, and might well have caused the formation of the plain from which these terraces were subsequently developed by erosion. Somewhat careful search fails to show glacial striæ on the stones of the gravel, but striæ were hardly to be expected even if the gravels be of fluvio-glacial origin.

Another fact which seems to favor the glacio-fluvial origin of these terraces is found in the relation of the Twin Lakes and Clear Creek moraines to the valley. At the time of the last glaciation the ice from the west pushed across, or nearly across, the Arkansas valley at these places, and must have blocked the valley to some extent. Now, the older drift shows that during the earlier glacial epoch the ice was even more extensive, and must also have obstructed the valley at these points. This would have given the main stream a lower gradient, if it did not dam it altogether, and so favored the deposition of the gravels above. If the valley was effectually dammed, lakes would have existed; but the main body of gravel does not appear to have been deposited while this condition existed, if it existed at all. Furthermore, it is not apparent that the dam could have been high enough at any time to hold the water up to the level of the high terraces.

That the high terraces are of great age is plainly shown by the oxidized and decayed condition of their materials, as seen in a number of fresh sections, especially about Malta. Again, the small streams from the mountains have cut valleys deep into the terraces, valleys which are much larger than those cut by similar streams in the late glacial drift.

Low terraces.—Outside of, and below, the high-terrace level there sometimes occurs a set of low terraces which bear the same relation to the last glacial moraines as the high terraces do to the older drift. They connect with the new moraines at their upper ends, and their materials are of the same lithological character as those found in the new drift. The physical condition of the material of these terraces corresponds to that of the new drift, and they have suffered an amount of erosion comparable to that which has effected the new moraines. The few available sections in the low terraces fail to show any striated stones, although plainly formed from the outwash of the new drift.

The relations of the low terraces to the new drift and of the high

terraces to the older drift seem to be analogous, and point strongly to the glacio-fluvial origin of both sets of terraces.

CHANGES IN DRAINAGE AFFECTED BY GLACIATION

Two clear cases of changes in drainage due to glaciation were worked out in this region. The Eagle River, one and a half miles below Pando (Fig. 2, *a*) enters a narrow rock gorge, about three miles

FIG. 2.—Sketch map of an area of about seventeen square miles near Pando.

a represents the head of the postglacial rock gorge entered by Eagle River a mile below Pando; *b* indicates the position of the probable preglacial course of the Eagle River. The dotted line represents the position of the moraine of the glacier which came down Homestake Creek.

long. In this gorge, the stream, although of considerable size, has cut itself only a shallow valley, which is clearly very young. Just west of the point where the stream leaves its broad valley for the narrow gorge, there is a low, broad, col (Fig. 2, *b*), filled with drift, beyond which lies Homestake Creek, which has, from this point down, a much larger valley than its size would require.

The history of the change seems to be as follows: As the ice of the last glacial epoch came down the valley of Homestake Creek, it pushed across the valley then occupied by the Eagle (Fig. 2, *b*) and by obstructing the stream, ponded it, and caused it to find a new outlet to the north. On the retreat of the ice, a drift dam was left across the old valley, and the Eagle continued to occupy its new channel as far as Redcliff, where it re-enters its old valley.

The second case is that of the Arkansas River,[1] the course of which was changed by the ice of the earlier (next before last) epoch of glaciation. The ice, advancing down the valleys of Lake and Clear Creeks, pushed across the Arkansas valley to the slope on the east side, and crowded the river up against the granite walls on that side, and even shifted it up somewhat on the other slope (see Fig. 1). At these places the river cut a new channel in the rock. From data gathered from borings at the placer mines west of Granite, it appears that the surface of the rock declines to the west for a considerable distance west of Granite (Fig. 1), indicating that the preglacial channel of the river was some distance west of the present river bed between Twin Lakes and Clear Creek. The river, being pushed over to the east at two points, may have had, at first, a great loop to the west between these points. If so, the curve may have been cut out and the channel straightened by piracy, or it may have been crowded over between the ice lobes, by fluvio-glacial deposition.

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[1] Professor L. F. Westgate, of Ohio Wesleyan University, was working upon this problem when the writers entered this portion of the field, and it is understood that he will publish his results on this problem in the near future. He had worked out the essential features of the changes in the channel of the Arkansas before the writers reached this part of their field.

THREE NEW PHYSIOGRAPHIC TERMS.

CERTAIN phases or types of topography, some of them widespread and all of them distinct, have no appropriate designation. Reference to them, where they have been recognized, has been by tedious circumlocution. Names for three such phases or types of topography are here proposed.

I. TOPOGRAPHIC UNCONFORMITY.

The essential idea underlying this term is a topography on the upper part of a slope, which is out of harmony with the topography on the lower part of the same slope. The slope may be that of a mountain, a hill, or a valley, or it may be the slope of a larger tract, such as a coastal slope. The lack of harmony may be brought about in various ways. The term has to do with the result, not the process by which it was brought about. Two illustrations are added.

1. When a mountain valley, the slopes of which are well dissected by rain and river erosion, is occupied by a thick and effective glacier, the ice is likely to obliterate many of the erosion features of the valley slopes, up to the limit of effective ice-action. The obliteration of the erosion features of the lower slopes is effected partly by erosion and partly by deposition. The result is that the more open, broad, and mature erosion features of the upper slopes are interrupted below at the upper limit of effective ice-action. The more open valleys and ravines above are continued below by the young, narrow, gorge-like drainage channels developed since the glaciation of the valley. These drainage lines of the lower slope are out of harmony with the drainage lines above. In such cases the topography above the limit of effective glaciation is in *unconformity* with that below. Topographic unconformity of this type is common in the western mountains. It may be seen, for example, about Telluride, Colorado, on the slopes above Lake Chelan, and in scores of other places. Fig. 1 shows a portion of the west slope of Lake Chelan near the south end. The topographic unconformity resulting directly from glaciation is somewhat overshadowed by the topographic unconform-

ity which resulted from the development of shore terraces in a lake which stood much higher than the present lake after the ice melted.

2. If a coastal region affected by well-developed valleys is submerged, the lower ends of the valleys become bays. Shore deposits may be made across the mouths of the bays, converting them into lagoons. The lagoons may then be silted up. If the region be subsequently elevated relative to sea-level, the streams coming down

FIG. 1.—The slope of Lake Chelan, showing topographic unconformity.

the mature valleys above cut new valleys across the new lands recently emerged. The result is that valleys and topography of greater or less maturity above are succeeded coast-ward by valleys and topography which are much younger. Fig. 2, from the coast of California, affords an illustration.

It is, of course, clear that the same sequence of events may affect a lakeshore, where it is clearly the level of the water which fluctuates. Illustrations of topographic unconformity are perhaps more readily drawn from lakeshores than from seacoasts, for notable changes of water-level are here more common. The borders of Lake Chelan, already referred to, furnish a good illustration, and the shores of

Lake Bonneville furnish others. (See Plates I, IX, XXI, XXII, XXVI, and XXVII, *Monograph* I, U. S. Geological Survey.)

In general, it may be said that any cause which brings about the relations indicated above—namely, greater topographic age on the

FIG. 2.—Topographic unconformity shown in contours, Oceanside, Cal., quadrangle. Scale, about one and one-fourth miles to the inch.

upper part of a slope, and lesser topographic age on the lower part of the same slope, with a distinct line or belt of separation between the two—develops *topographic unconformity*. If the relations were reversed, so that lesser age on the upper part of a slope was succeeded by greater age below, the two phases of topography being separated by a distinct line or zone, the result would also be a topographic

unconformity. This case is less common than the other, and, on the whole, less striking, since lesser age above and greater age below is the rule. In the normal case, however, there is no distinct line or zone of separation.

Another phase of topographic unconformity will be referred to under "Superimposed Youth."

II. TOPOGRAPHIC ADJUSTMENT.[1]

The term "adjustment," as applied to streams, has been long in use. A stream is said to be adjusted when it flows as little as possible on resistant formations, and as much as possible on weak ones. In general, adjusted streams follow the strike of the formations over which they run, and where they depart from it they are likely to do so by flowing with the dip for short distances. It is proposed to designate the above type of adjustment *structural adjustment*. Structural adjustment has to do with the courses of streams.

There is another type of adjustment, namely, *topographic adjustment*, which has to do with the profiles of streams. One or two illustrations will suffice to make the meaning of the term clear.

1. When a stream has a wide flood-plain, its channel is likely to be now against one bluff, now against the other. This is true of different parts of the valley at the same time, and of the same part at different times. When a stream flows against the bluff on one side for a considerable period of time, the tributaries adjust themselves *topographically* to this position of their main; that is, the lower end of each tributary has the same elevation as its main at the point of union, and the grade of the tributary above the junction is the grade normal to the stream. If now the main stream shifts to the opposite side of its valley, the tributary stream is thrown out of topographic adjustment. Its lower end is too low, for, essentially without grade, it must find its way across the wide flood-plain to the channel on the other side. The result is that the tributary aggrades its lower course until it has a proper gradient out to its main. When this is accomplished, *topographic adjustment* is established.

If now the main stream swings back again to the bluff which it temporarily abandoned, the tributary finds itself again out of topo-

[1] This term has already been published: CHAMBERLIN AND SALISBURY, *Geology: Processes and Their Results*.

graphic adjustment. Its lower end is now too high, and it sets to work to deepen its lower course. When the lower end of its channel is brought to the level of the main at the point of junction, and when its profile above is in harmony with the deepened lower end, the stream is again in topographic adjustment.

2. When falls recede past the debouchures of tributaries, the tributaries are no longer in topographic adjustment to their main.

3. The hanging valleys of glaciated mountain regions, and waterfalls are other cases of lack of topographic adjustment, or of non-adjustment.

Any other course of events which brings about similar results—and they may be brought about in several other ways—may be said to result in the topographic non-adjustment of streams.

III. SUPERIMPOSED YOUTH.

The terms "youth," "maturity," "old age," etc., as applied to rivers, are now in common use. There are certain phases of youth, however, which the term "youth," as commonly used, does not seem to define. In many parts of North America, for example, the topography was mature and the relief great when the ice of the glacial period came on. Partly by erosion and partly by deposition, the ice effected changes in the topography. As the ice retreated, drainage re-established itself on the modified surface.

It often happened in such cases that the old valleys were partially filled, without being obliterated. They were often filled deeply at some points, while they received little drift at others. Basins were developed, and in many cases these basins became the sites of lakes. The drainage which established itself in such regions after the ice melted has not in general had time to obliterate these marks of topographic youth, especially within the area of the last ice-sheet. The streams and valleys themselves have many of the characteristics of youth, such as falls, rapids, lakes at high levels, and, locally, narrow postglacial gorges. All this may be true while the mature topography of the underlying rock is but faintly masked. Considering only the greater features of the topography, there is the appearance of maturity; but when the minor features, such as lakes, ponds, marshes, falls, narrow postglacial gorges, and the peculiar uneroded,

or little eroded, topography of the drift are considered, youthful features are seen to abound. In such cases, *youth* has been *superimposed* upon maturity. It is proposed to call this phase of youth

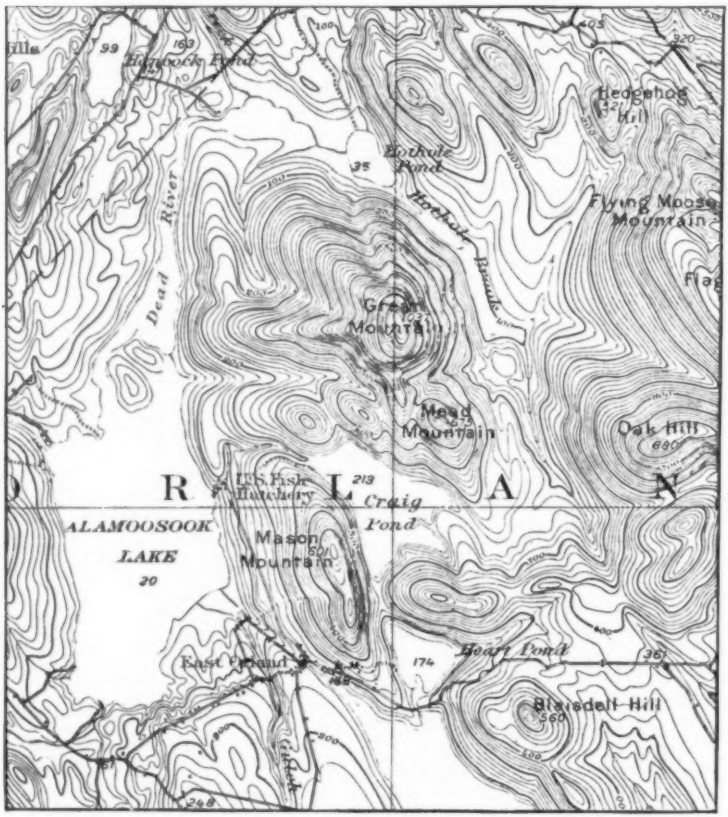

FIG. 3.—Superimposed youth, from the Orland, Me., quadrangle. Scale, about one and one-fourth miles to the inch.

superimposed youth. Fig. 3 furnishes an illustration. Good illustrations abound in the glaciated mountains of the East, and in many areas farther west.

In the foregoing case, youth was superimposed on maturity.

But the type of youth here referred to might be superimposed on a topography which was old, or on a topography which was young. Thus, when the upper, but not the lower, portion of a young mountain valley is severely glaciated, a topographic change is effected. The wide, open, U-shaped or cirque-like upper part of the valley which was glaciated, is often continuous below with a narrow valley of a very different type. In spite of the fact that the glaciated part of the valley is wide open, it possesses distinctly youthful characteristics. Even though the valley was youthful before glaciation, its youth has now assumed another phase. Here youth is superimposed on youth. Examples of this phase of superimposed youth abound in nearly every mountain range of the West where there were glaciers during the last epoch.

In the cases cited, the superimposition of youth has resulted from glaciation. Should it become desirable to distinguish between the youthfulness superimposed by different means, the type of superimposition cited above might be called *glacially superimposed youth*.

Between the *superimposed youth* of the upper glaciated part of the valleys cited in the above illustration, and the normal youth of the parts below, there are (1) a *topographic unconformity* and, (2) a lack of *topographic adjustment*.

THE NEED OF DISCRIMINATING TYPES OF YOUTH.

There are various types of topographic youth which need to be discriminated. Take, for example, the types of youth illustrated by the region about Fargo, N. D. (Fig. 4), and that shown along the shore of Lake Michigan just north of Chicago (Fig. 5). The former region has often been cited, and properly, as an illustration of topographic youth, but it hardly represents normal youth.

The different phases of youth shown by these two areas are always confusing to students at the stage when they are learning to interpret topographic maps. In the one case, young valleys are in process of normal development, and those which continue to grow should, in the course of time, acquire permanent streams. In the other, the surface came into possession of a well-developed stream somewhat suddenly, after the retreat of the ice. The meandering

course of the river, in the one case (Fig. 4), is often mistaken for a mark of age.

Special names for the types of youth illustrated by these two

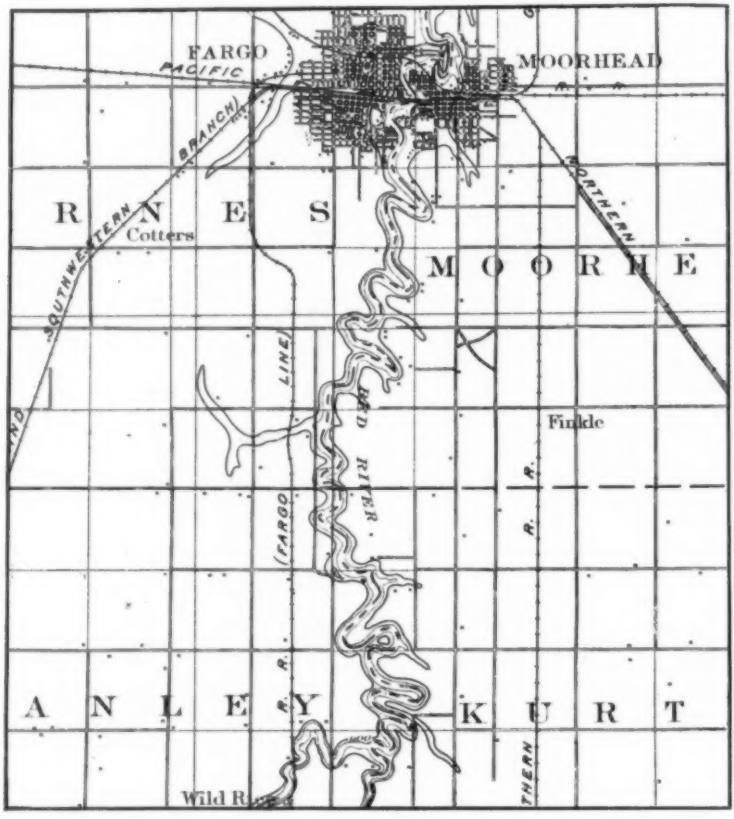

FIG. 4.—A type of youthful topography, from the Fargo, N. D., to Minnesota quadrangle. Scale, about two miles to the inch.

areas would be useful. If the type of topography represented in Fig. 5 be regarded as that of normal youth, that shown in Fig. 4 should be designated by some qualifying adjective. No fitting

FIG. 5.—A second type of youthful topography, from the Highwood, Ill., quadrangle. Scale, about a mile to the inch.

term has suggested itself. *Superimposed youth* hardly seems to be appropriate, for there is here no evidence, which the student who is not yet a master of topographic maps may recognize, that the stream has been superimposed.

ROLLIN D. SALISBURY.

ON CERTAIN ASPECTS OF THE LOESS[1] OF SOUTHWESTERN IOWA.

RECENTLY the Chicago, Burlington & Quincy Railroad has made some extensive cuttings on a new right of way in southwestern Iowa, affording thereby excellent opportunities for observations on the loess and the underlying till. These cuts are especially interesting on account of the varied aspects presented by the surface material overlying the glacial drift. Three sheets of loess in the same vertical section are discernible.

First, or uppermost, is the ordinary yellow deposit of the Missouri bluffs phase common at the surface everywhere throughout the region, and which needs no further description.

Underlying this loess is a loess of different character; it is whitish in color, and is more clay-like in texture than the ordinary deposit. It appears also to contain less calcareous matter. The white loess and the yellow loess are distinguishable, not merely in fresh section by their difference in color and texture, but also in weathered exposures by their different aspects. The yellow loess tends to assume that peculiar facies familiar to all who have seen the western phase of the loess, whereas the white loess displays more of the behavior of a joint clay, especially as regards superficial drying and cracking.

Below the white loess and in marked contrast with it in the matter of color is a red loess. This red loess occasionally contains a few calcareous nodules of the general appearance of loess kindchen; its lowermost six inches contain pebbles of various sorts, but these rarely exceed the size of a bean and are absent from the upper part of the deposit, as they also are from the white and the yellow loess. In texture the red loess resembles somewhat the white loess above it; it is apparently a little less clayey.

[1] It may not be out of place to remark that there seems to be a tendency to give the word "loess" a specific meaning rather than to assign to it a generic significance, which would be more desirable. To the writer loess means any considerable accumulation of surface material, eolian in origin, the component particles of which are too small to give the deposit the character of sand or grit. Subject to this limitation, loess may have any texture or any color, as well as any peculiarity of topographic facies.

Underneath the red loess is the pebbly till of the Kansan drift-sheet, which is here of the same general character as that everywhere seen throughout southern Iowa. It is the usual rock meal charged with erratics of every description; the uppermost three or four feet present the usual aspects of the ferretto zone so well described by the geologists of the Iowa survey. The color of this ferretto approximates closely that of the red loess above it, but there is never the slightest difficulty in distinguishing the line of demarkation. The leaching

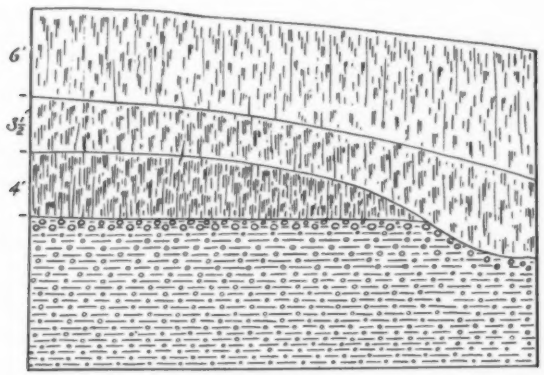

FIG. 1.—Section in railroad cut at Red Oak, Iowa, showing the three deposits of loess over the Kansan till.

and oxidation which produced the ferretto have left it mottled with white patches of kaolin, marking the site of former pebbles of feldspar. It contains also numerous pebbles of quartzite, greenstone, and other materials. Moreover, the exact line of demarkation is very frequently indicated by a layer of gravel and pebbles which owes its origin to the action of wind and weather on the long-exposed surface of the till, whereby the finer particles were removed and the coarser ones left behind as a mechanical concentrate. This phenomenon is similar to that observed at the contact of the upper surface of the Iowan drift with the loess in the paha region of the eastern part of the state.

As shown in the railroad cuts within the city limits of Red Oak,

the yellow loess, is, at a maximum, about twelve feet in thickness, the white loess about six, and the red about four or five. Westward of Red Oak both the red and the yellow loess increase in thickness relatively to the white loess, which finally disappears in this direction. The yellow loess then rests directly on the red loess. To the eastward of Red Oak the reverse is true; the yellow and the red both decrease in thickness. In a sixty-foot cut two miles east of Red Oak the red loess is wanting; the white loess, eight feet in thickness, rests directly on the ferretto. Near the Adams county line the yellow loess appears to be very much reduced. East of Corning the surface loess resembles the white loess and may be identical with it; the resemblance here imputed refers both to fresh and weathered sections.

The most favorable place for studying these deposits and the relations between them are: in the cut just east of the depot at Red Oak, south of the depot in the bluffs left in excavations made by the railroad for material for fills, and in the cuts on the divide between the East Nishnabotna River and Walnut Creek.

As regards the propriety of designating the white and red deposits herein described as loess, there can be little question. They are deposits of loess for practically the same reasons that have been urged in the case of the yellow loess, the eolian origin of which has now been conceded by most geologists. Like the yellow loess, they conform, blanket fashion, to the inequalities of the pre-loessial topography; like the yellow loess, they are invariably thickest on the crests and brows of the erosional hills carved out of the old Kansan drift-plain. They are not to be considered as of subaqueous origin for the reason that no conclusive evidence has been obtained that the region in which they are found was ever submerged beneath such a large body of water as would have been a condition necessary to their deposition.

The red loess is evidently no mere local deposit. It has been observed in Pottawattamie county, which lies north of Montgomery county, by Udden,[1] who describes it under the name of "gumbo."

[1] *Iowa Geological Survey*, Vol. XI, p. 255. The writer has examined the red deposit described by Udden as occurring under the yellow loess at Minden, and has satisfied himself of its loessial nature as herein defined. It may be remarked that the name "gumbo," as applied to the red loess, is apt to prove a confusing misuse of a

The reddish-yellow loess reported[1] by Udden from Mills county is probably a modification of the red loess; the ferruginous, weather-stained loess reported by Calvin[2] as occurring in Page county under the yellow loess, and separated from it by a layer of cross-bedded eolian sand, can scarcely be anything else. The white loess will probably be found to have a wide distribution; it, or a loess very much like it, is to be found under the yellow loess in Carroll county.[3] Bain and Tilton[4] have casually mentioned the occurrence of two sheets of loess at different points in southern Iowa. One of these is probably the white loess. The white loess is also reported from Pottawattamie county by Udden, who, however, thought it to be a modification of his gumbo. As the width of the area of overlap of these two sheets of loess appears to be rather limited, Udden probably did not see them in the same vertical section, and hence his failure to recognize them as distinct deposits would be accounted for. A very interesting suggestion is contained in the fact noted above, namely, that the red loess does not seem to extend far to the east of Red Oak, while the white loess apparently thins out to the west of the same place. The suggestion is that a deposit of loess may have fairly definite boundaries, which may be imposed on it by vegetation in much the same way as vegetation imposes limits to the spread of the drifting sand of a dune area.

The red, the white, and the yellow loess are not different phases of one original loess which has undergone secondary modification since its deposition. A view affirming the contrary would be negatived by the reflection that changes produced by weathering or interstitial deposition of material by infiltration would not be likely to simulate

term borrowed from agricultural terminology. "Gumbo" properly means a stiff, impervious, waxy, clay-silt, which the red loess certainly is not. It is an open question whether the red loess was deposited as such, or acquired its red color through subsequent oxidation of its iron content. On the other hand, there exists the possibility that it consists of the finer particles sorted out of the red ferretto and carried by the wind to new resting-places. It would therefore be local in origin; the other loesses are, however, clearly foreign.

[1] *Ibid.*, Vol. XII, p. 167. [2] *Ibid.*, Vol. XIII, p. 445.

[3] Verbal communication from Professor B. Shimek, and later verified by personal inspection. Both sheets of loess are well shown in the railroad cuts southwest of Carroll.

[4] *Op. cit.*, Vol. VII, p. 523.

ordinary bedding over wide areas. Conclusive evidence that each is a deposit *sui generis* is also afforded by their stratigraphic relations; all three deposits must be regarded as unconformable the one with the other as well as with the till. This is beautifully shown as regards the red and the white loess in the cut just east of the depot at Red Oak, where it may be seen that the red loess has been involved in erosion antedating the white loess, which fills a depression previously cut through the red loess into the till. Analogous evidences of a stratigraphic break between the white and the yellow loess are not wanting in the same neighborhood. In this connection the red loess observed by Calvin in Page county may again be referred to. The layer of eolian sand there separating the red loess from the yellow loess is additional, if slight, evidence of the time break between the two deposits.

The inferences to be drawn from the existence of these three sheets of loess and from their mutual relations are extremely interesting. Considered along with the cursory references of various geologists to the existence of distinct loess sheets in southern Iowa, it would appear that the real complexity of the loess can no longer be doubted; "the problem of the loess" becomes, in a new sense, one of magnitude and importance. Here, as elsewhere in geology, a stratigraphic break is a fact of prime significance. The deeply scored surface of the Kansan drift is clear evidence of a long period of time before new conditions brought on the red loess; the supercession of red loess deposition by an interval of erosion, followed by a period which witnessed the deposition of a new and different loess, is sufficient evidence that the interloessial period was long enough to bring about fundamental changes in governing geological conditions. The change from the white to the yellow loess has the same significance.

It may be permissible to remark that the development of our knowledge of the loess is perhaps now in about the same stage as was our knowledge of glacial drift just after its glacial origin had been established. At first geologists could see only one drift-sheet and did not dream of more than one ice-invasion. It was only after the complexity of the glacial deposits had been perceived that they were forced to those studies which have given us our present theories of glacia-

tion. It remains to be seen whether a general recognition of the complexity of the loess is to be followed by a satisfactory explanation of the loessial and interloessial stages. Iowa, which has become classic ground for the glaciologists, will undoubtedly afford much illuminating material to the students of the loess.

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THE EFFECT OF SUPERGLACIAL DÉBRIS ON THE ADVANCE AND RETREAT OF SOME CANADIAN GLACIERS.

OBSERVATIONS on rates of motion, amounts of advance or retreat of glaciers, and kindred statistics are now being collected from all quarters of the globe in the hope of deducing some general laws of ice-motion in the present, and of throwing some light on glacial conditions in the past.[1]

Obviously the advance of glaciers is influenced by two factors: (1) rate of motion, and (2) rate of waste. Any cause increasing the rate of motion will tend to push the front of the ice forward, and this advance will be held in check only by the amount of waste. Waste will be increased either by a rise in temperature, producing increased melting and evaporation, or by increased exposure to dry air producing evaporation. A glacier may advance, therefore, either from increased motion or from decreased waste.

Observations on the advance or retreat of existing glaciers have been correlated almost exclusively with the factors influencing rate of motion. The rate of waste is usually neglected, or is regarded as of secondary importance. Of secondary importance it may be in the case of any one glacier, since the daily and annual ranges in temperature about the freezing-point are approximately the same in successive years. Hence it may be safely assumed that the amount of water lost by any one glacier will differ from year to year mainly in proportion to changes in the mass of the ice, which in turn is affected by rate of motion. But when different glaciers are compared, it becomes evident that rate of waste is an important factor in determining the position of the ice-front.

Glaciers differ from each other in rate of waste, as they do in rate of motion, and a sluggish glacier, slow-moving and slow-wasting, may advance farther than one whose rate of motion is faster, but whose rate of waste is also faster.

[1] HARRY FIELDING REID, JOURNAL OF GEOLOGY, 1895 to date.

The several factors influencing the rate of melting will be discussed later. The one which it is especially desired to emphasize is the protective effect of a thick covering of débris.

It is a familiar fact that dust absorbs the sun's heat, causing melting, with the formation of dust wells, while larger fragments shade the ice, and may be left standing on protected pillars, the ice having melted around them. Sand and débris cones are formed in the same way, from the shading of the ice by a pile of material. Obviously, if this process were carried to an extreme, and the entire surface of the ice covered, the whole would be shaded, and hence protected from melting.

In regions where glaciers now occur (i. e., regions of high altitude or of high latitude) there are great contrasts in temperature between sun and shade. It frequently happens that this contrast involves a range above and below 32°, and that the temperature is below freezing in the shade when it is well above in the sun. A débris covering will protect a glacier from the direct sunlight, and may therefore keep its temperature below 32°, and so prevent melting.

Moreover, the daily range in temperature at the surface of the soil is much greater than the daily range slightly below the surface. A point below the surface will be shielded from extremes and will be colder during hot, and warmer during cold, hours, than the surface. In the case of glaciers, a débris covering protects the ice from the air of the surface. Hence in times of extreme cold the protected ice will be warmer than the surrounding air; in times of heat it will be colder. Since in regions where glaciers now exist, the yearly temperatures below 32° are greater in number and in amount than those above, this protection from the air will be of more avail to prevent melting than to cause it.

It is therefore to be expected that protected glaciers should advance farther down their valleys than if not so protected, and that the retreat of protected glaciers would be slower.

In the mountain region of British Columbia and Alberta there are many hundred existing glaciers. This region is one of especial interest to the glacialist in that it appears to be the center from which came the lobes of a large part of the Cordilleran ice-sheet. The highest parts of the mountains were never covered by ice, nor

does there seem to have been formerly any common direction of movement. In the past, as at present, glaciers moved toward all points of the compass, and the present glaciers may be regarded as the actual remnants of the upper portions of the great glaciers of the past.

The Canadian Pacific Railway affords easy access to many of these glaciers. It crosses the mountains near the fiftieth parallel, and at this point the glaciers are confined to a belt about one hundred miles wide, within the Rocky and Selkirk ranges.

The valley glaciers near the line of the Canadian Pacific may be classified into two groups. These groups are primarily geographical, being respectively east and west of the continental watershed, but the glaciers of these two groups have striking physical differences also.

GLACIERS OF THE CENTRAL AND EASTERN ROCKIES

The valley glaciers of this region have little or no névé portions, being fed by avalanches from overhanging cliff glaciers. These avalanches carry down great quantities of bowlders, mixed with the ice and snow, with the result that glaciers of this type are covered throughout almost their entire length with a thick mantle of débris. The cliff glaciers have névé portions, but the topography is such that large snow-fields do not accumulate. The cliff glaciers rest on exceedingly steep slopes, usually terminating upward in arêtes, so there is little place for the accumulation of snow. It is characteristic of this region that its glaciers consist of an upper névé and cliff portion with very high gradient, separated by a fall from a lower débris-covered valley portion.

GLACIERS OF THE WESTERN ROCKIES AND SELKIRKS

These glaciers have very large snow-field and névé regions, and such material as they carry is largely subglacial or englacial. In their method of formation these glaciers resemble the typical valley glaciers of Switzerland, but differ in that they are proportionally broader and shorter. In this region one névé may feed many glaciers, whereas to the east many cliff glaciers feed a single valley glacier.

Of late years Messrs. George and William S. Vaux[1] have recorded

[1] GEORGE AND WILLIAM S. VAUX, "Observations on Glaciers in British Columbia," *Proceedings of the Academy of Natural Science*, Philadelphia, 1899.

observations on the Illecillewaet, or great glacier of the Selkirks. Their observations include a measurement of the rate of motion of different parts of the ice by means of iron plates fixed on the surface, and also a record of the retreat of the ice front since 1887. They record a few observations on other glaciers, but these are of a more general character. In 1888 Dr. William S. Green made a single measurement of the rate of movement of the Illecillewaet.[1]

These observations appear to be the only ones on record. In the face of such sparse statistics, generalizations seem premature;

FIG. 1.—Victoria Glacier, showing level surface, and cliff glaciers on Mount Lefroy.

nevertheless, one fact is evident, namely, that the glaciers on the east, which are covered with débris, are either advancing or retreating slowly, while those on the west, with clean surfaces, are retreating rapidly.

GLACIERS OF THE FIRST GROUP

Victoria glacier (*Fig. 1*).—This glacier is now well known to tourists, lying at a short distance from one of the Canadian Pacific Railway châlets, and being the feeder of the now famous Lake Louise. As seen on the map (Fig. 2), it is short and wide, and has two branches, which come from the south and the east repectively. These branches are fed by avalanches from the cliff glaciers of

[1] GREEN, *Among the Selkirk Glaciers* (Macmillan, 1890).

Mounts Victoria, Lefroy, and Aberdeen, and except in its upper portions, the glacier is covered with débris. The glacier is nearly flat, and each of its upper ends entirely fills its valley. Snow and rock from avalanches form a heterogeneous pile on the surface, snow predominating at the ends and the sides of the upper portions. This snow is rapidly melted by the heat of the sun, and a short distance from the upper ends is a region of small ice pillars. As the lower end is approached, surface débris increases, until at the extreme

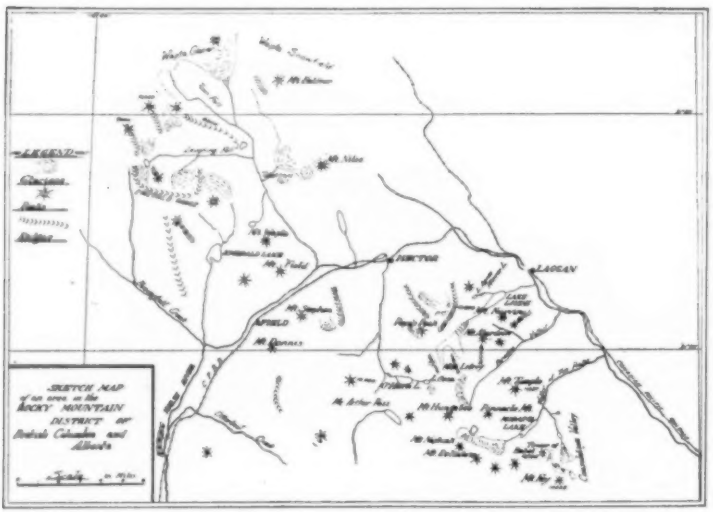

FIG. 2.—Sketch map of area referred to in text.

end it is in most places impossible to tell where the ice ends and moraine begins.

In recent geological time this glacier was evidently of much greater extent, but in the immediate past it extended only a short distance farther than at present. It has left a series of recessional moraines, but these are close together, often crossing or ramifying. Closely bordering this recessional belt are fair-sized trees, and beyond these trees no moraine is found. Glacial material is abundant throughout the valley, but beyond the moraines it is in a secondary position, deposited by water. Of late, therefore, the glacier has retreated but little.

It is a notable fact that the Victoria glacier does not face directly down its valley, but diagonally across it, the ice-front facing the northwest. The high cliffs of Aberdeen keep off the early morning sun, so that even in midsummer the sun does not strike the glacier before 7:30 A. M., and then at first only the northwest side. The direction faced by the ice-front is thus determined, not by the direction of motion, but by the position of maximum melting.

As already stated, the end of the ice is mainly buried in moraine, but at two points ice is exposed. At both points the face is steep,

FIG. 3.—Front of Victoria glacier, showing its steep face, diagonal position in the valley, and terminal moraine.

exposing the laminæ of ice. In this respect it resembles high-latitude glaciers, rather than the usual alpine type (Fig. 3).

The surface of the Victoria glacier is very flat, the angle of profile rarely exceeding 8°. This flat surface makes an angle with the steep front somewhat exceeding a right angle.

During the year from July, 1899, to July, 1900, Mr. Vaux found that a marked bowlder in a central position on the ice moved 147 feet. One at the edge moved 115 feet. Shrinkage for the year was only 6 feet.

Glacier of the valley of the Ten Peaks.—This glacier occupies a valley parallel to that of the Victoria glacier, some ten miles to the southeast. Moraine Lake lies in this valley a short distance below

the glacier, the glacier itself being confined to the southeastern side of the upper end of the valley. This glacier closely resembles the Victoria, but has a few points of difference. The cliff glaciers which feed it are on the southeastern side of the valley. Opposite these cliff glaciers, on the northern side, are talus-covered slopes. The talus also apparently occupies a portion of the valley bottom, and here meets some old and very angular débris. A small lake occupies the valley bottom at an elevation of about 7,000 feet. It is surrounded by talus and débris on three sides, the fourth being the rock of Mount Pinnacle. This lake appears to be fed by a sub-talus inlet, the greater part of its water coming from the side of the glacier. This glacier, then, is fed not only at its end, but from its southern side, and water issues not only at its front, but at points along the northern side.

Its surface is covered with débris more deeply than that of the Victoria glacier. The rock masses are remarkably angular and often of great size. In several places piles of débris have accumulated, protecting the ice beneath and forming rock cones.

This glacier is remarkable in that it is advancing, both down the valley and also laterally on its northern side. For the lower mile of its course it is now overriding a large forest. Unfortunately, no data are on record concerning its rate of advance or its rate of motion.

In a pamphlet on glaciers Mr. Vaux remarks concerning this glacier: "At some date, not very remote, an unusual avalanche of rocks of enormous proportions has buried the ice deep in piles of huge stones and bowlders which, preventing the access of the sun's rays, protect it from much melting." It is hardly necessary to postulate an *unusual* avalanche. The cliffs south of the glacier are tremendous, and the rock, a thick-bedded limestone, weathers along its joint planes into large rectangular blocks which are continually falling to the glacier below. In this weathering process not only the cliff glaciers, but also gravity and the great daily range in temperature, are effective.

The fact that the glacier fills only the southern part of its valley seems due to the same cause that leads to the diagonal fronting of the Victoria glacier. The ice is shaded by high cliffs on the east and

south, and when the morning sun finally strikes it, the first portion to be touched is the northern side. This glacier also has little fall, and its front is steep. Its valley is terraced and shows evidence of occupation by a great glacier in the past, and Moraine Lake is held up by a débris dam; but there are no modern terminal moraines other than the one now being formed. This glacier, therefore, is larger at present than at any very recent time. It is a significant fact that this glacier, which is advancing, should be much more deeply covered with débris than other similar ones which are retreating slightly.

FIG. 4.—Front of glacier in Consolation Valley, showing its steep face, and terminal moraine in the lake.

Glacier in Consolation Valley.—Consolation Valley is the largest tributary of the valley of the Ten Peaks. It is similar to the two preceding valleys in the presence of lakes in the lower part of its course, and of a débris-covered glacier at its head. This glacier seems to be little visited, and was omitted entirely from the Canadian survey map (Lake Louise sheet, 1902).

The trend of the valley is northward; consequently the glacier is not shaded in the early morning. As a result, it faces directly down its valley. At its upper (southern) end this glacier begins in two alluvial cones which meet from opposite sides of the valley. It is fed mainly from its southwestern end and side, from cliff glaciers on Mount Fay (Fig. 4). Cliffs bound its southwestern side, and from these cliffs several alluvial cones extend, in some cases reaching the ice and loading it with material. The consequence is that the glacier is streaked with ridges of material of various kinds and colors, according to the source. These ridges bear a general resemblance to

medial moraines. Between the ridges the ice is comparatively clean and has melted so that the débris stands up on ridges of ice.

A remarkable feature of this glacier is the presence of several lakes on the ice. Their basins apparently began as transverse crevasses, and grew by melting. Their walls are vertical, and display the synclinal structure of the ice, with the drift covering on the surface. There are several lakes in various stages of growth, the process being that of melting away beneath, the top being shaded by débris, and the result being the production of a nearly round lake from a long narrow one. The largest of these lakes measured about 500 feet by 300 feet.

FIG. 5.—Lake on the ice of the glacier in Consolation Valley, showing the synclinal structure of the ice and the débris covering.

Débris was constantly falling into this lake. The layers of ice could be plainly seen (Fig. 4). The lamination was due mainly to differences in consistency of the ice. The amount of interbedded material was small, but was all concentrated along definite layers.

The lower end of this glacier was more completely covered with débris than the upper part, the streaks of different colors being pushed close together. The glacier ends in a lake, a nearly perpendicular cliff of ice rising from the water. Here also the layer of ice may be seen (Figs. 5 and 6).

One recessional moraine is present, extending in a peninsula from the shore of the lake into the water. On the shore the northern edge of this moraine is bordered with bushes, and there are no other recent moraines. It is therefore evident that this glacier is only a few feet shorter than at the time of its recent maximum extension.

Features common to the preceding glaciers.—These glaciers each have a main line of drainage coming from beneath an arch of ice, but only a portion of the drainage comes directly into this channel. Water escapes through the bordering débris at the front and sides, and can often be heard trickling beneath the drift. The subglacial drainage of the Victoria glacier has been changed, a long cave showing the position of a former exit. No superglacial drainage was observed.

It is characteristic of all of these glaciers that their gradients are

FIG. 6.—Glacier in Consolation Valley.

low; that their centers are but slightly higher than their sides; that their fronts are nearly vertical; and that of late they have retreated little, if at all. The cliff glaciers which feed them are 2,500 feet or more above the level of the valley glaciers below, and the lower limit of the glaciers is at about 6,000 feet.

The material with which their surfaces are covered is angular and talus-like. It is frequently stated that superglacial material is highly oxidized, and that by this characteristic it may be distinguished from subglacial material in the deposits of the glacial epoch.

Among the glaciers of the eastern Canadian Rockies the superglacial material accumulates by falling on the ice in steep, narrow valleys, as in the instances just described. In no case was the amount of oxidation found to be extensive. It was usually apparently less

than in ordinary talus slopes, for in falling 2,000 feet or more the bowlders often break and gain unweathered surfaces. But in shape there is a conspicuous difference between subglacial and superglacial fragments. The superglacial material retains its angular form, and is dropped in the terminal moraine without scratches, while the subglacial material is worn and grooved. The result is that those parts of the moraine which are composed of superglacial débris resemble talus, and can be distinguished from it only by their topography.

FIG. 7.—Cliff glacier of Mount Victoria, and the side of the Victoria glacier.

The glaciers described above represent the type in this region. Several other glaciers of the same type were seen by the writer, but only one of them lay west of the continental divide. This one is at the head of Lake Oesa.

The steep front characteristic of these glaciers is a feature that has hitherto been recorded only in the case of high-latitude glaciers. Steep fronts are characteristic of both cliff and valley glaciers in the Canadian Rockies, and are due to different causes in the two cases. In the cliff glaciers the steep front of the ends comes from the periodic breaking off of the front of the glacier, the broken end falling over a cliff and leaving a vertical ice face on the glacier (Fig. 7). It occasionally happens that the slopes of mountains on which cliff glaciers rest are bounded by cliffs on several sides. In such cases the cliff glaciers

may acquire steep sides as well as steep ends by this breaking off process. When the rock sides are higher than the floor beneath the ice, the sides of the cliff glaciers are buried in snow, and so, either actually or apparently, are not steep.[1] In the valley glaciers the steep end has some other cause which appears to result from a combination of shape and manner of melting.

FIG. 8.

These glaciers of the central and eastern Rockies remain approximately constant in thickness, melting on the surface at their upper ends, and beneath the surface at their fronts. The regions of accumulation and of maximum surface melting are similar. Fig. 8 shows diagrammatically the front of one of these glaciers. The upper layers are protected from melting, hence remain intact at the front, while the melting of the lower layers leads to the formation of a cliff and of an angle between surface and front. Glaciers of the ordinary alpine type push forward, at a high gradient, from a region of perpetual snow, melting at the surface and thinning toward their lower ends. Fig. 9 represents the front of one of these glaciers. The end slope may be as steep in the second case as in the first, but there is invariably the difference that among these glaciers there is a gradual curve from surface to end, while among those of the first group there is a sharp angle between a nearly horizontal surface and a nearly vertical front. The slope of the front of the second type of glaciers is determined in part by the gradient of their beds, in part by the rapidity of surface melting at the front. Among glaciers of the first type, slope and surface melting are both at a minimum, and the angle of the front is determined by rate of sub-surface melting.

FIG. 9.

Steep sides as well as steep ends are characteristic of high-latitude

[1] Cliff glaciers were defined by Salisbury in this JOURNAL, 1895, p. 888. The cliff glaciers in Alberta are of a slightly different type from those described from Greenland. They form in essentially the same way, but the ends of the Canadian cliff glaciers usually push over the ends of precipices and break off, leaving several hundred feet of vertical ice which forms an ice-cliff above the rock cliff. Those figured by Salisbury appear to end like steep alpine glaciers. Another point of difference is that these Canadian cliff glaciers lie on the general slope of the mountain and are much broader than they are long, while those in Greenland lie in steep gullies.

glaciers. Among the eastern Canadian glaciers the sides are almost invariably buried either in talus from cliffs or in moraine (Fig. 7). Among the glaciers above described the glacier of the valley of the Ten Peaks, which is advancing laterally, is the only one in which the ice of a side was visible. In this case the side was steep, like the front.

GLACIERS OF INTERMEDIATE CHARACTER

It is impossible to draw a hard and fast distinction between these two types of glaciers, since there are many glaciers, parts of which belong to one type and parts to the other. But in each case it was evident that whenever glacier ice was buried sufficiently to shut out sun and air entirely, surface melting practically ceased.

The Yoho Valley lies on the western side of the continental divide. Though a tributary by name, it furnishes the greater part of the water supply of the Kicking Horse River. The Yoho Valley is a glacial canyon, with rock terraces on its sides. There are six large glaciers on the sides of the Yoho Valley, the water from these glaciers coming over the terraces in falls. One important tributary enters the Yoho from the west. At its junction with the Yoho this tributary forms the Laughing Fall; farther up its course five glaciers lie on its sides.

The glaciers of the Yoho are fed by large snow-fields, for the most part yet unmapped. As a rule, the surfaces of the glaciers are steep, clean, and much crevassed, and their ends have the gradual curve from surface to front illustrated in Fig. 9. The sides of the valley are so steep that the fronts often have a high angle, and ice cascades occasionally occur.

Most of these Yoho Valley glaciers belong to the second type, but three of them combine the characteristics of the two groups. These three lie on the sides and end of Laughing Fall Valley.

One of these glaciers on the north side of Laughing Fall Valley enters its basin over a col between two limestone peaks. Its general direction of flow is eastward over the col; then it cascades over a cliff forming some fine seracs, and turns southward toward the Laughing Fall Valley. The eastern slope of the basin of this glacier, is formed by shale ridge locally called "The Whaleback." The ice, in turning the corner just described, banks itself up against "The Whaleback" and becomes buried in shale. With the shale are mingled rounded limestone fragments from the peaks to the west, the débris being

frozen into the ice and forming a sort of conglomerate. The surface is thickly covered also. The ice thus loaded and protected seems entirely stagnant, neither moving nor melting. The main body of the ice, however, was clean-surfaced. Several recessional moraines showed its retreat.

Similarly a glacier extending northward from Emerald Mountain showed several recessional moraines on its western side, while the eastern portion, which was buried in talus, appeared to be stationary.

At the head of this same Laughing Fall Valley lies a lake, about a mile in length. Its outlet is over rock, its eastern and northern sides are of rock, while its western side is formed by a débris-laden glacier. Besides the ice is a brook, the lower course of which is arched over by snow. The snow patch ends in the lake, and portions of it break off and float away like small icebergs. The glacier appears to be advanced as far as it ever was. There is no moraine in front of it, and no débris could be seen in the water of the lake. Since the water of the lake is remarkably clear, any débris that had been dropped in it could have been distinguished.

The débris of this glacier is apparently derived directly from the mountain behind it, without the assistance of cliff glaciers. This point, in which these three Yoho glaciers are alike, is an important difference between them and the glaciers of the first group. Although resulting in a preservation of the ice in both cases, it is in the Yoho an exceptional and unusual occurrence, while among the glaciers first described the débris covering comes as a necessary part of their mode of origin.

The Lake Louise sheet of the Canadian Survey map, though accurate near the railroad, is in the Yoho Valley entirely a work of imagination. The lake at the head of Laughing Valley, and five large glaciers are omitted entirely, while the position of mountains and slopes of valleys are inaccurate. The sketch map (Fig. 2) accompanying this paper is adapted from this sheet.

GLACIERS OF THE SECOND GROUP

Glaciers of the Yoho Valley.—At the head of Yoho Valley is the Wapta glacier (Fig. 10). This glacier is fed by a great and yet unmapped snow-field. The glacier itself is broad and short. Its

slope is steep; its surface clean and much crevassed; its front, though steep, does not exhibit a cliff.

No records are available as to its rate of motion, but a rapid retreat is evident. Drift material, free of vegetation, is to be found for about three-quarters of a mile from the ice and extending 300 feet up the sides of the valley. The ice descends to a level of 5,000 feet (aneroid).

FIG. 10.—Wapta glacier.

Fed by the same snow-field is another glacier which descends the valley above Twin Falls. This valley is flat and open, the glacier having less slope than the Wapta, and for some reason which is not evident the ice-front does not descend below 5,700 feet. A recent rapid retreat is evident, but the exact amount could not be determined, since fresh landslides have brought down much material which has been mingled with the drift, while both drift and talus are being worked over by the glacial stream.

The Illecillewaet glacier.—Probably the most famous and most often visited glacier in British North America is the Illecillewaet, or

Great Glacier, of the Selkirks (Fig. 11). At a distance of only two miles from the railroad, the glacier is easily reached by a good trail.

It is fed by a snow-field which forms a plateau at a level of about 7,000 feet. From this névé the glacier descends in a great ice cascade to a level of 4,750 feet. Its surface is perfectly clean and much

FIG. 11.—Illecillewaet glacier.

broken, seracs and crevasses being abundant. Its front is very little steeper than the average slope of the glacier.

In 1888 Dr. Green found that in twelve days the center of the ice moved 20 feet; the side, 7 feet.[1] Since 1887 Messrs. George and William S. Vaux have made a special study of this glacier. The general average of their observations shows a motion of from 6 to 2 inches daily in different parts of the ice. The great difference between these figures and Dr. Green's may be due to some change in conditions, or to the observations having been taken on different parts of the ice. At all events, Dr. Green's figures seem too high

[1] *Among the Selkirk Glaciers* (Macmillan, 1890).

for the present motion. Since the beginning of the observations of Messrs. Vaux the end of the glacier has been receding rapidly. A general average of their observations gives an annual recession of about 60 feet.

The Illecillewaet névé is some 10 square miles in extent. It lies in a depression between several high peaks, and feeds four large glaciers. A second of these is the Asulkan. During the year 1899–1900 Mr. Vaux reports that this glacier receded 24 feet, but at present it seems to be advancing. When I visited it this summer, the end had pushed forward up and over an old moraine.

The Asulkan and Illecillewaet glaciers are roughly parallel, both moving north. From the same névé comes the Geikie glacier, moving southwest, and the Deville glacier, moving east. There are several lesser, unnamed glaciers at intermediate points. All present the same general characteristics of high gradient, clean surface, and rapid retreat.

CONDITIONS AFFECTING MOTION

Without entering into the causes of glacier motion, it is safe to say that the conditions favoring rapid movement are steepness of slope, great precipitation of snow, little load, and high temperature.

Slope.—The slope is greater in glaciers of the second type than in those of the first type. The Victoria, Ten Peaks, and Consolation Valley glaciers on the east side are almost flat. They appear to lie in valleys of slight declivity, and the continual melting at their upper ends keeps the ice of nearly uniform thickness. But glaciers of the second group have, as a rule, great slopes. The Illecillewaet rises over 2,000 feet to its névé, in a distance of about two and one-half miles. The Wapta is almost as steep, rising about 1,200 feet. The Asulkan has a varied course, having two falls separated by a flatter area, but its general slope is steep. This steepness of slope is due partly to steep declivity of the valley floors, partly to great thickness of the ice in the region of accumulation, with thinning from melting in the region of dissipation. Both from steeper slope of the valley and from greater pressure of a thicker mass of ice above the glaciers of the second type have the advantage.

Snowfall.—Records are kept at the Glacier House with more or

less regularity. The station is nearly 3,000 feet lower than the Illecillewaet névé. The amount of precipitation received by the glacier is therefore probably greater than that of the valley. An average of seven years' observations gives an annual snowfall of 36 feet and 5 inches.

No records are kept in the immediate vicinity of the Rocky Mountain glaciers. Records here would be of less significance, for precipitation is exceedingly local in character. Moreover, owing to the occasional occurrence of Chinook winds, there is far greater evaporation than in the Selkirks. It is safe to say that here, as elsewhere in the Rockies, there is far less precipitation than among the mountains to the west, and that there is more evaporation.

The prevailing winds coming from the west and from the sea, the moisture is first precipitated on the westernmost mountains. As they progress eastward, the prevailing winds have less moisture. Having less moisture, the daily range in temperature becomes greater, and the difference in temperature and in precipitation between valley and mountain slopes, greater. In the Bow Valley, near the glaciers of the first group, the maximum depth of snow in winter is said to be 2 or 3 feet; on the slopes near the glaciers of the same region, 10 or 15 feet. The depth of snow on the ground in the Selkirks, near the Glacier House, is 20 feet or more.

Load carried.—It has been shown by I. C. Russell,[1] and also by Messrs. Chamberlin and Salisbury,[2] that glaciers heavily loaded with débris move more slowly than those which have no load. This is due in part to the lessening of the viscosity of the ice by the introduction of rigid material, and in part to the formation of débris-charged ice-dams at the ends, which hold back the advancing ice. So far as could be observed, the amount of englacial material is small in both types of Canadian glaciers, and there is probably little difference in viscosity from this cause. But it is common for the glaciers of the first type to end in a mass of ice thickly charged with débris and forming a sort of ice conglomerate. This was the case also with the three débris-charged glaciers of Laughing Fall Valley;

[1] JOURNAL OF GEOLOGY, Vol. III (1895), pp. 823–32.

[2] *Ibid.*, 1894–95.

but only in one instance, the side of the Illecillewaet, was it evident among glaciers of the second type.

Thus all the conditions affecting rate of motion are in favor of the glaciers of the second type. They have greater slope, more snowfall, and less retarding load. According to the very meager statistics, their rate of motion is about five times as rapid as that of the glaciers of the first type.

CONDITIONS AFFECTING WASTE

Since, therefore, the glaciers of the second type are retreating with much greater rapidity than those of the first, more waste must be looked upon as the cause. The factors which affect rate of waste may be summed up under (1) amount of rainfall; (2) daily and annual range of temperature above the freezing-point; (3) altitude of the snow-line; (4) topography; (5) amount of sunlight and of air received by the ice.

Rainfall.—The records at the Glacier House show an annual rainfall of 12.98 inches. This amount is too small to be a large factor in wastage, especially when contrasted with the great snowfall. The only records kept in the Rocky Mountains localities are notes of the number of rainy or showery days. These notes show considerable variation in different years, but afford no data for comparison with the western region.

Range of temperature.—For the past seven years records have been kept at the Glacier House. From the end of October until the beginning of March the maximum temperature is below freezing. In March, April, September, and October the average temperature is near the freezing-point, either above or below. In the summer months it is above, with an absolute maximum of 86°. The daily range is 10 to 20°.

At Banff records are kept in the office of the Rocky Mountains Park of Canada. There is much more variation in temperature here, and the daily range is greater, and sometimes involves a rise above the freezing-point in winter. In midwinter temperatures of +40° are not uncommon. The daily range is from 20 to 40°, and sudden intense cold may be followed by warm Chinook winds.

The two climates are in a general way similar. Winter has

practically the same duration at Banff as at Glacier; the absolute maximum temperature at Banff (July 4, 1903) is recorded as 81.8.° The length of hot and cold seasons is approximately the same, and the range above freezing is practically the same.

Such differences as there are would favor a more rapid waste among the first type of glaciers. Occasionally midwinter temperatures above freezing would favor melting; the warm, dry Chinook winds would favor evaporation. Since, therefore, these glaciers are wasting with less rapidity than those of the second type, there must be some other cause than the temperature of the two regions.

Altitude of the snow-line.—In the Selkirks the snow-line is at an altitude of about 7,000 feet. From this level the glaciers descend with a fall of from 1,000 to 2,500 feet.

In the Rockies the snow-line is higher. It is variable, but is in general at an altitude of about 8,500 feet. The débris-covered glaciers end at a level of about 6,000 feet.

Topography.—The general effect of the occupation of a valley by a glacier is to round its outline, changing a V to a U in cross-section. The extent to which this can take place depends (1) upon the structure and character of the rock, and (2) upon the erosive capability of the glacier. The schists and quartzites of the Selkirks are readily rounded, and broad open U's produced in a relatively early stage of erosion. The result is the production of wide areas in which the accumulation of snow is possible. These gentle-sloped depressions aid the great precipitation and low snow-line in the production of the great névé regions.

The Rockies, in the region of the first type of glaciers, are composed for the most part of hard unmetamorphosed limestone, with vertical cleavage. Its tendency is, on weathering, to produce cliffs. The resulting valleys are steep-sided canyons even after their occupation by ice. Any widening out that takes place is below the snow-line, and impossible for névé formation. The small size and sluggish character of the glaciers may be effective of the same result.

The only points of lodgment for snow and ice are in cracks in the faces of cliffs, and here are found the only névés of the region, as feeders of the cliff glaciers. Thus precipitation, altitude of the snow-line, and topography combine to form great névés in the one

region; to prevent this formation, in the other. The result of this method of formation is that the valley glaciers on the east are entirely in the region of melting, and that the new snow supply they receive has no connection with their own forward movement.[1] It might therefore be expected that their rate of melting would be greater than that of the glaciers with great névé regions as reservoirs of accumulation. That this is not the case seems to be due entirely to the remaining factor of waste.

Amount of sunlight and of air received by the ice.—There are two causes which combine to shade the eastern glaciers: (1) shading by the steep cliffs, and (2) covering by débris. The shading by cliffs seems sufficient to determine the general position of the ice in its valley. This position of equilibrium once determined, the débris covering becomes the determining factor. That it is so is shown by the melting of the inter-débris areas, and its effectiveness is due to protection from both melting and evaporation.

GENERAL CONCLUSIONS

The type of glacier here described under the first group is not a common one, and probably exists only in regions of sharp relief and moderate precipitation. Less relief would afford opportunity for snow-fields to accumulate; greater snowfall would fill the valley, connecting the valley glacier with the cliff glaciers above, and so keeping the débris subglacial throughout. Either cause would produce a glacier of the second group—the ordinary type. Among glaciers of this ordinary type the concentration of débris on the surface at the lower end is a part of the process of retrogression, representing a stage of decadence.[2] The ice, if thus protected, is nearly stagnant, and the thickness at the lower end is relatively less than that of a vigorous glacier. This is clearly not the case with the glaciers of the first group; the ice is in motion, its slow movement coming from slight slope and slight pressure; the débris is superglacial; the thickness at the lower end is considerable, and the front

[1] Except in form these glaciers might properly be classed with Piedmont glaciers, which they strikingly resemble. See Russell, "Malaspina Glacier," *Journal of Geology*, Vol. I.

[2] I. C. Russell, *American Geologist*, Vol. IX (1892), pp. 322–36.

is in some cases advancing. These facts show the glaciers to be vigorous and not in the last stages of decline.

The great changes in glaciers come as a response to climatic changes. Slight climatic oscillations take place in periods of about thirty-five years, and now is about the time when a glacial advance is expected. But the advance of these glaciers cannot be due to any such climatic change. Since the winds are deprived of their moisture by the mountains to the west, it is the western glaciers which should first respond to any such change. With the exception of the Asulkan the western glaciers mentioned are all rapidly retreating.

It would thus appear that the débris covering, and that alone, is responsible for the advance, and indeed for the continued existence, of the glaciers of the eastern Rockies.

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Reviews.

A Treatise on Metamorphism. By Charles Richard Van Hise. (Monograph XLVII, U. S. Geological Survey.) Washington, D. C. Pp. 1,286; 13 plates. $1.50.

This treatise is an attempt to reduce the phenomena of metamorphism to order under the principles of physics and chemistry, or, more simply, under the laws of energy. Metamorphism is broadly defined to include all alterations of all rocks by all processes. The metamorphism of the sedimentary rocks was the first subject studied by the author, and metamorphism has been a chief line of investigation with him for more than twenty years. Finding that the alteration of rocks was nowhere systematically treated, he took up the task of preparing such a work. It was supposed that this work would occupy two or three years, but, as a matter of fact, it required seven years, and an eighth year has been needed to put the volume through the press.

The book consists of twelve chapters. Chapter 1 discusses the geological principles upon which a classification of metamorphism may be based. From this discussion it is concluded that the only practicable classification of metamorphism is geological. It is found that the alterations of the outer zone of the earth are radically different from those of the deep-seated zone. Moreover, it is shown that the alterations in the upper zone result in the production of simpler compounds from more complex ones, while those in the deep-seated zone result in the production of complex compounds from more simple ones. The upper zone is called that of katamorphism, and the lower zone that of anamorphism.

Chap. 2, upon the forces of metamorphism, discusses chemical energy, gravity, heat, and light. The manner in which each of the classes of energy produces various mechanical and chemical effects upon rocks is set forth.

Chap. 3 treats of the agents of metamorphism. The agents of metamorphism are gaseous solutions, aqueous solutions, and organisms. Under aqueous solutions the chemical and physical principles controlling the action of ground water and the circulation of ground water are fully discussed. This involves a full résumé of the science of physical chemistry, so far as applicable to the alterations of rocks. This résumé is not simply a summary

from textbooks of physical chemistry, but discusses the applications of the principles to the phenomena of metamorphism.

Chap. 4, upon the zones and belts of metamorphism, discusses these zones and belts from the physical-chemical point of view. It is shown that the alterations of the zone of katamorphism occur with liberation of heat and expansion of volume, the chief reactions being oxidation, carbonation, and hydration. The alterations of the zone of anamorphism occur with absorption of heat and diminution of volume, the chief reactions being deoxidation, silication with decarbonation, and dehydration. Thus the alterations in the two oppose each other. The zone of katamorphism is divided into two belts—that above the level of ground water, the belt of weathering, and that below the level of ground water, called the belt of cementation. While the physical-chemical principles of alteration are the same in each of these belts, the geological processes are very different. The belt of weathering is characterized by solution, decrease of volume, and softening, resulting in physical degeneration. The belt of cementation is characterized by deposition, increase of volume, and induration, resulting in physical coherence.

Chap. 5 treats of minerals. Each of the rock-making minerals is discussed with reference to its occurrence and alterations. The alterations are considered from the physical-chemical point of view. An attempt is made to write chemical equations which represent the transformations, and to calculate the volume relations resulting. It is found that a great number of rock-making minerals undergo two classes of changes, one of which is characteristic of the zone of katamorphism, and the other of which is characteristic of the zone of anamorphism. Perhaps the most important generalization of this chapter is as to the reversibility of reactions in the two opposing zones. This generalization is as follows: The equations which represent the reactions in the zone of katamorphism are reversible in the zone of anamorphism; and, so far as there is expansion of volume and liberation of heat in the upper zone, just so far is there condensation of volume and absorption of heat in the lower zone.

Chap. 6 considers the belt of weathering. The belt of weathering, being the one which is most readily observed, has been treated by many authors. The chapter in this volume on weathering differs from previous discussions in that the phenomena are not considered mainly from the descriptive point of view, the emphasis being given to the classification of the phenomena and their explanation under physical and chemical principles. Also an important feature of this chapter is the consideration of the phenomena of the belt of weathering in relation to the alterations of the other belts of metamorphism.

Chap. 7 treats of the belt of cementation. This belt is defined as extending from the belt of weathering to the bottom of the zone of fracture. The geological results are found to contrast very markedly with those of the belt of weathering. In the latter belt solution is the rule; openings are enlarged; the rocks degenerate. In the belt of cementation, on the other hand, the processes of metamorphism continuously deposit material, the openings are closed, and thus the rocks are consolidated. Each of the cementing substances is considered, and an explanation is offered as to why cementation rather than solution is a general process in this belt.

Chap. 8 treats of the zone of anamorphism. This is the zone in which rock flow occurs. Full explanations of the meaning of rock flow and of the development of such secondary structures as slatiness, schistosity, and gneissosity are offered. Perhaps the most important generalization is that rock flow is mainly accomplished through continuous solution and deposition, that is, by recrystallization of the rocks through the agency of the contained water. But rock flow is partly accomplished by direct mechanical strains. At the beginning of the process, during the process, and at the end of the process, the rocks, with the exception of an inappreciable amount, are crystallized solids.

Chap. 9 treats of rocks. A classification of the sedimentary rocks is given, their genesis is discussed, and the series of transformations through which each of the rocks passes is traced out, the resultant rocks being indicated. It was not found possible to give a similar treatment for the igneous rocks.

With the ninth chapter the subject of metamorphism proper closes, but the results contained in these nine chapters have an important bearing upon other parts of physical geology. The remaining chapters consider these relations.

Chap. 10 discusses the relations of metamorphism to stratigraphy. It is shown that in consequence of metamorphism great difficulties are introduced in stratigraphical work. The nature of the difficulties and the manner in which they may be overcome are fully considered.

Chap. 11 treats of the relations of metamorphism to the distribution of the chemical elements. This is perhaps the most daring of the various attempts at generalizing of the treatise. It is shown that as a result of the forces and agents of metamorphism the elements of the original igneous rocks are redistributed, a given element being less abundant in the larger number of sedimentary rocks than in the original rocks, and corresponding with this depletion each of the elements is segregated in one or more formations. An attempt is made to treat the problem of the redistribution of the elements quantitatively. Assumptions are made as to the total mass of the

sediments and of the relative proportions of the more important classes of sediments. Combining these assumptions with the results of chemical analyses, the losses and gains of various formations for each of the important elements of the earth are considered. Many surprising results are reached. For instance, we find the conclusion that to oxidize the ferrous iron of the original rocks to the ferric condition in which most of it occurs in the sedimentary rocks, 35 per cent. of the amount of oxygen in the atmosphere has been required. But still more startling is the conclusion that to oxidize the sulphur and iron of iron sulphides in order to produce the sulphates of the ocean and gypsum deposits, and to transform the iron to the ferric form, required one and one-half times the amount now in the atmosphere.

The final chapter of the book, 12, is upon the relations of metamorphism to ore deposits. It is probable that this chapter will receive more general attention than any other. The material of the other chapters is of a kind which is likely to be of interest to the geologist only, whereas this chapter is of interest to all men concerned in the great mining industry. The chapter on ore deposits occupies 240 pages, and, indeed, might have been named "The Principles of Ore Deposition." From the author's point of view, the majority of ore deposits are produced by metamorphic processes. Having worked out the general principles of metamorphism with reference to rocks, the author found that the application of these principles to ore deposition explained the majority of ore deposits. From his point of view the proper theory of ore deposition consists mainly in bringing the particular phenomena exhibited by ore deposits under the general principles of metamorphism. The chapter contains a new classification of ore deposits, the fundamental divisions of which are the same as those of rocks. Thus ore deposits are divided into three classes—those of sedimentary origin, those of igneous origin, and those of metamorphic origin. Strictly the treatise on metamorphism should, perhaps, have considered only the third class. However, the first and second classes are sufficiently discussed, so that the relations of these ores to those produced by metamorphic processes may be appreciated. The discussion of ore deposits is too elaborate to be summarized in this general statement. But it may be remarked that for the metamorphic ores an attempt is made to trace out the solution, transportation, and precipitation of each of the chief economic metals. Also the alterations and further segregation of metals are fully considered. The conclusion is reached that in many cases an ore deposit does not represent a single segregation, but is the result of repeated segregations by the same general processes which result in the depletion in certain elements of the various rock formations and their segregation elsewhere. In other

words, the principles of the development of ore deposits are the principles of the segregation of those elements which are of importance to man, but which, for the most part, are so rare that they are not included in the discussion in the chapter on the redistribution of chemical elements.

It is not possible in a summary to give any adequate idea of the scope of this treatise on metamorphism. A very broad range of facts, extending far beyond what might at first be regarded as a part of a treatise on metamorphism, is considered from the energy point of view. It is believed that the volume marks a great stride in the reduction of the entire subject of physical geology to order under the principles of physics and chemistry, and points out the way for a treatment of the entire subject from this point of view. K.

The Stone Reefs of Brazil, Their Geological and Geographical Relations, with a Chapter on the Coral Reefs. By JOHN CASPAR BRANNER. (Bulletin of the Museum of Comparative Zoölogy, Cambridge, Mass., 1904.) Pp. 285, 91 plates.

THIS contribution stands almost in a class by itself in that it adds a new variety to the recognized type-formations. While reefs of this class have not been wholly unknown to geologists, they seem to have been regarded rather as individual aberrancies than as expressions of a type dependent on regional conditions and prevalent within the range of those conditions. They have, indeed, been mentioned more or less frequently, but oftenest in such a way as to carry the suggestion that they were coral reefs or some modification of such reefs due to accessions of hardened sand. Their distinctive nature and its peculiarity was recognized by Darwin, Hartt, and a few others, but this comprehensive treatment by Dr. Branner is the first exposition that has brought forth their broader relations and their true significance; indeed, it is the first that has made clear the essential fact that they are not mere aberrant phenomena, due to a fortuitous combination of local conditions, but rather a type of formation, albeit a rare and regional one. While not confined to the coast of Brazil, these sandstone reefs are so limited and peculiar in their distribution, so far as present knowledge goes, as to give special interest to their localization. In the opinion of the author, this regional localization carries genetic significance, and the discussion of this forms a most interesting feature of the book. The peculiarities of these reefs are summarized by the author as follows:

I. They are of sand consolidated to a hard—in places almost quartzitic—sandstone.

II. They stand about flush with the water at high tide, while at low tide they are left exposed like long, low, flat-topped walls, with a width of from five meters to one hundred and fifty meters, and a length of from a few paces to several kilometers.

III. They accompany the shore-line with many and great interruptions from north of Ceará to Port Seguro, a distance of two thousand kilometers.

IV. With unimportant exceptions, the reefs do not occur along the Brazilian coast beyond these limits.

V. They usually stand across the mouths of streams and estuaries, forming perfect natural breakwaters for the small harbors behind them. Sometimes they follow the shore, either on the beach or at a short distance from it.

VI. They are all nearly straight. When crooked, their curves are gentle.

VII. The structure and position of the reefs and the animal remains they contain show that they have been made by the lithification of beach sands in place.

VIII. When stone and coral reefs occur together, the stone reefs are inside or landward of the coral reefs. It is possible, however, that there may be buried coral reefs in some cases to the landward of some of the stone reefs.

IX. The coral reefs are now growing over and upon the stone reefs in some places, while at other places there are stone reefs overlying dead coral reefs.

X. In general appearance, elevation, and position the sandstone reefs bear a striking resemblance to the coral reefs.

The characteristics of these reefs are set forth by careful detailed descriptions, unusually well illustrated by excellent sketches, cross-sections, outline maps, coast charts, and photographic plates (104 figures, 99 plates). The treatment also includes the discussion of several collateral themes, among which are the coast changes, concerning which the following conclusions are drawn:

1. There is no evidence of a perceptible change of level of the coast since the discovery of Brazil.

2. Changes have taken place in the form of the coast-line, and in the adjacent streams, bays, and estuaries in historic times, but they are all accounted for by the ordinary processes now in operation.

3. The stone reefs are not metamorphosed or folded, and they do not rise above tide-level, except in a few instances, where blocks have been tilted by the undermining done by the waves.

4. The coast lakes have been formed by the damming in of estuaries, by the sands blown along the coast, and by the throwing back into the estuaries of detritus cut by waves from adjoining headlands or brought down by streams from the land.

5. The straightness of the coast-line is due to the long period of wearing to which the coast has been subjected, and to the constant on-shore winds and waves along the coast.

6. During the dry season the waves of the sea are able to close the mouths of many of the weaker streams.

7. At such times only the large streams are able to keep their mouths boldly open.

8. Although no changes of level are known to have taken place within the historic period, there are evidences of both elevation and depression of the Brazilian coast in late geologic times.

9. The evidences of depression consist of:

a) The open bays: Rio de Janeiro and Bahia.

b) The partly choked up bays, such as Santos and Victoria.

c) The coast lakes formed by the closing of the mouths of estuaries, such as Lagoâ Manguaba, Lagoâ do Norte, Jiquiá, Sinimbu, etc.

d) Embayments altogether filled up.

e) The islands along the coast are nearly all close in-shore and have the appearance of having been formed by depression of the land.

f) The buried rock channels at Parahyba, now filled with mangrove swamps and mud, show a depression of at least twelve meters since those channels were cut.

g) Wind-bedded sand below tide-level on Fernando de Noronha.

10. The evidences of elevation consist of:

a) Elevated sea beaches, especially well shown about the Bay of Bahia, and along the coast of the state of Bahia.

b) Marine terraces about Ilheos in the state of Bahia. These are about eight meters above tide-level.

c) Horizontal lines of disintegration about one meter above high tide in granites and gneisses at and about Victoria, state of Espirito Santo.

d) Burrows of sea-urchins so far above low tide that sea-urchins cannot now live in them. These are well shown at Pedras Pretas on the coast of Pernambuco.

11. Of the two movements the depression has been much the greater and was the earlier.

12. The great depression probably took place in early Pliocene times (see chapter on Geology, pp. 8–33).

13. Following the Pliocene depression of the coast, the headlands were strongly eroded, the mouths of bays and estuaries were closed, and the coast line was straightened.

14. The standstone reefs of the coast were formed and hardened subsequent to the depression.

15. The coral reefs of the coast have helped build out the shores, and they have likewise protected the land from the destructive action of the waves.

16. The stone reefs have also protected the land, and have helped to prevent the encroachment of the sea.

17. The mangrove swamps have been important agents in building up the newly formed land about estuaries and embayments.

18. The sands of the coast are not of foreign origin, as has been surmised, but are derived from the adjoining headlands, or they have been brought down from the land by streams.

The discussion of the consolidation of the reefs and of the origin of the cementing material is very full and able, assembling and treating critically and judicially a wide range of data and of phenomena, with ample references to the literature of the subject. One of the most interesting points is the relation of the density of the sea-water to the deposition of calcium carbonate, and the genetic connection of the stone reefs with the density of the adjacent oceanic waters and with the surrounding climatic conditions. The conclusions relative to the consolidation of the reefs are as follows:

Stone reefs are formed where there are streams or lakes of fresh water entirely or partially restrained by the beach sands. The new reefs may be formed either in front of the old ones, or in the embayment and estuary behind the older ones. For similar reasons, stone reefs may form behind or landward of the coral reefs. This can only happen, however, in places where marine currents prevent the land-water from interfering with the growth of coral reefs.

The local lithification of the sea beaches is not uncommon, but the most noteworthy instances of lithification on a large scale are those of the northeast coast of Brazil and of the Levant.

The cementing material of the Brazilian stone reefs is chiefly lime carbonate.

The hardening of beach sands may be produced in the following ways:

1. By carbonated rain-water dissolving out the lime carbonate in the upper portions of calcareous sands and depositing it in the lower portions.

2. By the escape of carbon dioxide from the sea-water when the surf breaks upon the beaches.

3. By the escape of carbon dioxide from sea-water where it is warmed by the tropical sun.

4. By the submarine escape of carbon dioxide about volcanic vents.

These processes may have contributed somewhat to the hardening of the Brazilian reefs, but they do not seem competent to account for them altogether. These theories are especially incapable of accounting for the lithification of beaches behind older reefs.

The distribution of the consolidated beaches of northeast Brazil leads to the inference that the consolidation is directly related to the density of the sea-water. The geology and climatic conditions over the adjacent land are, however, important factors in the hardening of the reef sands. It seems probable that the consolidation of the reef sands would not take place if the rainfall were large enough and constant enough to keep the mouths of the streams open and the water of the streams fresh.

In a region of concentrated rainfall and long drouths the river mouths become temporarily closed, and the abundant aquatic and other life in the lagoons thus formed contributes to the organic acid of the waters which, upon penetrating the wall or dam of beach sand, first dissolves the lime, and then redeposits it when it comes in contact with the dense sea-water on the ocean side. In this manner some portions of the beaches have been hardened, while others have remained incoherent.

The density of the ocean water is in all probability considerably greater during the dry than during the rainy season, and this would still further hasten the consolidation of the beaches during dry seasons.

The process of beach-hardening is not a continuous one, but varies with geographic and climatic conditions. New reefs may be formed behind the older ones on the shores of the estuaries and embayments.

The monograph is closed by a chapter on the associated coral reefs.

T. C. C.

The Copper Deposits of the Encampment District of Wyoming. By ARTHUR C. SPENCER. (Professional Paper No. 25, 1904.) Pp. 107; 2 plates and 49 figures.

THE district of which Mr. Spencer treats in this report comprises some 450 square miles in southern Wyoming, so situated that the southern boundary of the area lies close to the Colorado line, while the one hundred and seventh meridian bisects it. The encampment district is crossed diagonally from southeast to northwest by the irregular line of the Continental divide, which is the crest of the Sierra Madre Mountains. The maximum elevation is 11,007 feet (Bridger Peak), and the minimum 6,650 feet.

The structure is essentially a low arch or anticline whose axis is parallel with the mountain crest, that is, east-west. The core of this arch is made up of a mass of hornblende schists and sedimentary rocks, closely folded and overturned to the north, the whole forming a complex east-west synclinorium. These rocks are said to be pre-Cambrian, though the reasons for this conclusion are not given. They were invaded at a later period by basic igneous rocks related to gabbros. The hornblende schists appear everywhere to be the basement upon which the sediments were laid down.

Flanking these pre-Cambrian rocks is a series of Mesozoic and Cenozoic sediments which are now confined to the southwestern part of the area, as a remnant of a great mantle of sediments that formerly covered the whole arch. These formations dip away to the south beneath the surrounding prairie. The oldest of these formations is the "Red Beds" series of the

Trias. Above these lie Jurassic, Cretaceous, some small patches of Tertiary strata, and, on the higher elevations, glacial deposits.

The pre-Cambrian rocks and the intruded gabbro are the most important from the standpoint of the economic geologist, for it is with these that the ore deposits are connected.

As indicated by the title of the paper, copper ores are the chief ores of this district, though some lead and silver, and a trifling amount of gold, in quartz veins, have been found. The copper minerals comprise chalcopyrite, bornite, chalcocite, and covellite, with their usual alteration products. The principal gangue minerals are quartz, calcite, siderite, feldspar, hornblende, epidote, and garnet.

Some of the metallic sulphides crystallized contemporaneously with the silicate minerals of the rocks; others are supposed to be of later origin, and to have been formed by impregnation of the schists by the intrusive norite. A common origin by aqueous deposition is assigned to the remaining ores, and they are found in all channels of easy circulation. Their ultimate source is attributed to the basic igneous rocks of the region, which contain appreciable amounts of copper, and in many cases cobalt and nickel as well.

The most important ores commercially are those (chalcocite) found along the bedding planes and brecciated zones in the pre-Cambrian quartzite. Here secondary enrichment has taken place.

W. D. S.

Recent Seismological Investigations in Japan. By BARON DAIROKU KIKUCHI. Private Publication.

THIS important paper was prepared as an address to be delivered at the Congress of Arts and Science at St. Louis, but, as the author was unexpectedly prevented from attending the Congress, it was printed privately and distributed by him. It is, however, a much more elaborate paper, and much more amply illustrated, than would be inferred from the statement that it is an address. It covers 145 pages, and is accompanied by 54 illustrations relating to earthquake effects, earthquake-proof structures, instruments of observation and their records, geographic distribution, and related subjects. The paper sets forth with much fulness the work of the Earthquake Investigation Committee of Japan in connection with the Seismological Institute of the Tokyo University—work which must be regarded as among the most important now in progress. A chapter is given to the geographical and chronological distribution of earthquakes—

subjects to which the records of this "land of earthquakes" make exceptional contributions. Under the time distribution, the annual, diurnal, lunar, and other periodicities are considered. The most impressive feature of the geographical distribution lies in the fact that the frequency of the Japanese earthquakes increases toward the sea border, especially toward that portion of it which overlooks the great "deeps," and not toward the mountainous axis of the islands.

The instruments used in Japanese investigations are described, illustrated and discussed, as well as the nature of the oscillations which they detect and record.

In the discussion of the velocities of propagation of the seismic vibrations to distant points, preference is given to the view that the paths are essentially parallel to the surface, and not chords, as held by Milne, Knott, Dutton, and others (see previous review). The grounds for this are not made quite clear; at least they are not quite clear to the reviewer. The view involves the supposition that the ratio of elasticity to density in the different horizons near the surface of the earth varies so greatly that, while the main vibrations move at about 3.3 kilometers per second, the advance tremors move at about 14 kilometers per second, or more than four times as rapidly. Professor Nagaoka's investigations of the elastic constants of rocks (see table in Dutton's work, pp. 230, 231) give computed velocities for the fastest or normal wave ranging from 1.19 to 7.05 kilometers per second, the average of sixty-seven determinations made upon various surface rocks being 3.85 kilometers per second. When some little allowance is made for the fractured condition of the crust, this tallies well with the observed superficial rate of propagation, 3.3 kilometers per second. Selecting the Archean and eruptive rocks as being more nearly representative of the material of the sub-crust, eighteen determinations give an average velocity of only 3.75 kilometers per second. The compact Paleozoic rocks prove to be as elastic as the eruptives. The average of the highest eight of the whole list is only 4.95, or a little more than one-third the maximum velocity of the preliminary tremor. If the velocities of these select examples were computed for an unlimited rock medium, instead of a bar, they would average 5.79 kilometers per second, which is still less than half the requisite velocity. As no single rock was found to have much more than half the requisite velocity computed on the assumption that the preliminary tremors went around the spheroid parallel to the surface, and as the speed of the fastest form of wave in an unlimited medium of *steel* under surface pressure is theoretically only about 6.2 kilometers per second, it seems a rather arbitrary assumption that any substratum in the outer part of the earth

would give so high a velocity as 14 kilometers per second. On the supposition that the line of propagation is a chord, a velocity of 9.25 kilometers per second is required, which might more easily be supposed to be supplied by the high pressure of the deep interior, since pressure seems to increase rigidity faster than it does density (Dutton's work, p. 234). The most probable path is a chord-like curve convex toward the center of the earth, so chosen automatically by the wave as to give the most effective combination of shortness of path and superior elasticity, since the latter probably increases toward the center so as more than to overbalance the increased density. So far as giving us light on the physical condition of the interior is concerned, it is of the most vital importance that the correct interpretation of the path pursued by the vibrations be entertained.

The address brings out the gratifying fact that collateral investigations on the associated geological conditions, the earth's magnetism, gravity, underground temperature, and other related subjects, are being made by the Earthquake Investigation Committee. They are also engaged in practical studies for the reduction of the disastrous effects of earthquakes, and structural plans for houses are discussed and illustrated in the paper.

T. C. C.

Earthquakes in the Light of the New Seismology. By CLARENCE EDWARD DUTTON, Major U. S. A. New York: G. P. Putnam's Sons; London: John Murray, 1904.

THIS is a very lucid, appreciative, and trustworthy exposition of the recent important advances in seismology, and is in every way a most welcome contribution to the literature of the earth-sciences. Geologists have only partially realized the profound contribution which the new seismology is in process of making to the fundamental concepts of geology. It is perhaps necessary to guard the statement by saying that seismology is in the process of making, rather than has already made, a profound contribution to geologic fundamentals, for the contribution is dependent on the correctness of the belief that seismic vibrations pass *directly through* the body of the earth, as well as around its surface, and that the traversing waves are those that are first recorded by seismographs at distant points on the surface. It cannot as yet be absolutely affirmed that these preliminary vibrations actually traverse the deep interior. This is the interpretation of most of the leading seismologists, and is probably the correct one. Still it must be recognized that this is not yet proved, and that Baron Kikuchi (see preceding review) and others hold the view that these vibrations pass

around the centrosphere in a rather deep portion of the crust rather than directly through the body of the earth. So, too, it is necessary still to speak qualifiedly, for the chief value of the anticipated seismic contribution depends not only on the verity of the passage of the foremost vibrations through the heart of the earth, but also on the transverse character of the second set of these vibrations; for transverse vibrations are functions of solid bodies, but not of liquids, and hence their significance relative to the physical state of the interior. When it shall be shown beyond reasonable doubt that the second set of the transmitted seismic vibrations are transverse, and that they have passed through the center of the earth, it will have been shown with equal conclusiveness that the earth is solid throughout, save for such local spots as vulcanism requires, which would not affect the general power of transmission. Major Dutton brings out the data bearing on this chief point of fundamental interest carefully and conservatively, and makes them readily accessible to the geological inquirer who is not in possession of the special seismological literature. As best interpreted at present, the data seem to indicate not only a thoroughly rigid earth, but one in which there is an increase of elasticity of form toward the center in a ratio at least as high as the increase in density. This last is determined by the speed of wave-transmission, which is made the subject of three chapters.

While these difficult themes of supreme interest to the student of geological fundamentals are given due place in the later chapters of the book, they are not allowed to displace the more superficial and impressive phenomena that have given to earthquakes their universal, if somewhat gruesome, interest. The descriptions of the destructive effects are ample, but always clothed in chaste and sober scientific terms. The illustrations are select, and expressive of definite rather than promiscuous effects.

Much space is given to the instruments used in the more refined observations that characterize the new seismology, and to the methods by which the science is being advanced. The causes of earthquakes occupy a chapter; their distribution and geographic relations occupy two, and the book is closed by a chapter on seaquakes, the distinctness of which from earthquakes is usually overlooked. The treatment, while careful and exact, is not mathematical, except in a few cases where accurate expression would otherwise be impossible. The literary elegance which graces all of Major Dutton's writing finds as large an expression here as the nature of the subject permits.

T. C. C.

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THE

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